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AIRCRAFT ENERGY CONSERVATION DURING AIRPORT GROUND OPERATIONS

James S. Bauchspies
Frederick A. Costello
Joseph Felder
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FINAL REPORT

March 1982

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Office of Environment and Energy
Washington, D.C. 20591

NOTICE

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16. Abstract

This study identifies and assesses potential fuel conservation options which are available for use during ground operations at Dulles International (IAD) and Washington National (DCA) airports. The study also identifies and analyzes ground operations fuel savings options which have been considered and/or implemented by the various airlines operating at IAD and/or DCA since 1971. In addition, an evaluation of computer models which could be used for analyzing these fuel conservation options at other airports is included. The impact of socio/economic factors such as safety, environment, limitation on expansion and restrictions on accommodating forecast activity at DCA and IAD were considered during the analysis of each option.

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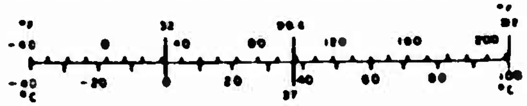
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10 000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

This report on "Aircraft Energy Conservation During Airport Ground Operations" presents the results of an assessment of promising procedural, operational and airport layout changes that are or could be used to conserve fuel during ground operations at Washington National (DCA) and Dulles International (IAD) Airports.

Data generated and analyzed in four previous task reports formed the basis for the material contained herein.

This effort was performed by ORI, Inc. under FAA Contract DTFA01-80C-10132.

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EXECUTIVE SUMMARY

This report presents the results of an ORI, Inc. analysis of current and potential fuel conservation or fuel management practices or techniques which have been or could be instituted by the Government and/or the airlines specifically for the purpose of achieving fuel savings during ground operations at Washington National (DCA) and Dulles International (IAD) airports. This is the final report of a five task effort performed by ORI under FAA Contract DTFA01-80C-10132. It consolidates the information previously reported in the Tasks 1-4 reports which analyzed particular aspects of the overall problem of fuel conservation during aircraft ground operations. Specifically, the previous tasks focused on the following:

Task 1 - On-Site Investigations and Baseline Estimate

Under this task, ORI and its subcontractor, Trans Systems Corporation, measured aircraft taxi times under varying meteorological and operating conditions by airline and aircraft type at DCA and IAD. Operations data were compiled for annual, quarterly, and peak month and peak day. Fuel flow rates were determined and algorithms developed for computing a baseline estimate of energy consumption during ground operations for 1979 (the base year).

Task 2 - Current Fuel Savings Practices and Procedures

In this task, ORI conducted a survey of the airlines which operate at IAD and/or DCA to determine the extent to which they use one or more of

five techniques specified by the FAA to conserve fuel during ground operations. The techniques were: starting engines during pushback, taxiing out and in with one or more engines shut down, most direct routing, gate hold procedures and fuel load planning practices. Fuel consumption was computed for each of the five scenarios and compared with the baseline estimate to determine the fuel savings that are currently being achieved as well as the potential fuel savings that could be achieved if all the airlines used the procedures one hundred percent of the time. In addition, the social/economic impact these techniques have on the environment, the traveling public and the airlines were analyzed and reported.

Task 3 - Evaluation of Computer Models

Under this task, ORI together with its subcontractor, Frederick Costello Incorporated, evaluated the current and potential capability of existing computer models to simulate the on-site measurements and fuel burn compiled by ORI and thereby enable computation of the estimated fuel benefits at other airports of interest.

Task 4 - Promising Fuel Conservation Options

This task expanded upon the Task 2 efforts to include promising procedural, operational and/or airport layout changes that could reduce fuel consumption at DCA and IAD. Social/economic factors were also evaluated as well as the costs, benefits and feasibility of implementing the options. The report concluded with areas in which additional study effort is recommended. The objective of these studies would be to obtain knowledge that is presently not available and/or to explore implementation problems.

DATA COLLECTION

An ORI project team consisting of ORI and Trans Systems Corporation personnel observed and recorded outbound taxi and inbound taxi times during on-site visits to DCA and IAD airports during the month of November 1980. Visits were scheduled to assure measurements would be made during both VFR and IFR meteorological conditions and during peak and non-peak hours during the day. Measurements were also made on both weekdays and on Saturdays and Sundays to determine the impact these factors would have

on taxi times. In all, four visits were made to IAD and six visits were made to DCA. Data was collected under the traffic and meteorological conditions as shown in Table ES.1.

In addition to the ORI effort, the FAA Technical Center was involved in a separate delay study at DCA. The ORI project team assisted the FAA Technical Center collect data at DCA during the week of 17 November 1980. This data was used to supplement the ORI data.

Details of the procedures used by the ORI project team to collect the taxi data are contained in Appendix A.

BASELINE ESTIMATE

The baseline estimate of fuel consumed at IAD and DCA during aircraft ground operations was computed by multiplying the time in mode (measured by ORI during on-site visits to the airports) times the fuel flow rate for a particular aircraft times the number of operations per year. The time in mode was a weighted figure which considered variations in the airline/aircraft taxi times collected by ORI caused by different meteorological conditions (e.g., IFR/VFR, day/night) and operational conditions (e.g., runway used, peak/non-peak traffic conditions). Fuel flow rates were based upon published flow rates for the type and number of engines for the airline/aircraft of interest as well as the average gross weight of the aircraft during take-off and landing operations. In most instances, the aircraft were found to be able to taxi at idle power; however, in some instances, especially those aircraft equipped with the CF-6 engine series, a higher power setting was required. To this fuel consumption was added the extra fuel required for the pilot to initiate aircraft roll and accelerate to taxi speed. This value was based upon a weighted parameter derived from the number of times a particular aircraft was observed to have held during taxi.

Annual operations data was obtained from FAA sources and disaggregated by ORI by airline and aircraft type. A complete discussion of the procedures used to determine operations data is contained in Appendix B.

TABLE ES.1

SCHEDULE OF VISITS TO DCA & IAD AIRPORTS AND ASSOCIATED TRAFFIC AND METEOROLOGICAL CONDITIONS

	MONDAY		TUESDAY	WEDNESDAY		FRIDAY			SATURDAY		SUNDAY		
	1600-1700	1700-1730	1100-1135	1000-1130		1300-1600	1600-1700	1700 1730	1330-1645	1645-1730	1100-1700		
Dulles International Airport													
IFR	X	X											
VFR			X	X		X	X	X	X	X	X		
Peak	X	X					X	X					
Non-Peak			X	X		X			X	X	X		
Day	X		X	X		X	X		X		X		
Night		X						X		X			
Predominant Runway	01	01	01	01		19	19	19	19	19	19		
				1130-1600	1600-1740	1325-1600	1600-1730	1730-1805	1410-1715		1255-1500	1500-1600	1600-1740
Washington National Airport													
IFR												X	
VFR				X	X	X	X	X	X		X		X
Peak					X		X	X					
Non-Peak				X		X			X		X	X	X
Day				X	X	X	X		X		X	X	X
Night								X					
Predominant Runway				36	36	18	18	18	36		18	18	18

No attempt was made to consider fuel savings options for the baseline estimate. The baseline estimate is shown in Tables ES.2 and ES.3.

CURRENT FUEL SAVINGS PRACTICES AND PROCEDURES

At the request of the FAA, ORI evaluated the extent to which five fuel savings procedures were being implemented by the airlines and calculated the fuel savings currently being realized as well as the potential fuel savings that could be realized if the procedures were fully implemented. The procedures evaluated were:

- Starting engines during pushback
- Taxiing out and in with one or more engines shut down
- Planning landing roll, turn-off and taxiing to the terminal with the most direct routing
- Gate hold procedures
- Fuel load planning practices.

The degree to which the air carriers use these procedures was based upon an ORI survey of the airlines and is shown in Tables ES.4 through ES.6. Different techniques are used for north versus south operations at DCA and are so reported. Detailed information for each airline is contained in Appendix D.

PROMISING FUEL SAVING OPTIONS

In addition to the five fuel savings procedures described above, ORI also evaluated other promising fuel conservation options which might prove feasible for implementation at DCA and/or IAD. These options were categorized as to procedural (i.e., those which could be implemented by the FAA), operational (i.e., those which could be implemented by the airlines), and layout changes in airport design and/or facilities.

An option was considered promising if it could be implemented and could produce significant fuel savings. Implementation difficulty was a major factor in the consideration since an easily implemented option could prove more promising than another option with greater fuel savings although more difficult to implement.

TABLE ES.2

BASELINE ESTIMATE DCA (Kg)

AIRCRAFT/CATEGORY	TOTAL	AIR CARRIER	AIR TAXI	GA
Annual	20,853,901	20,103,097	232,083	518,721
Quarterly				
1st	5,109,206	4,925,259	56,860	127,087
2nd	5,213,475	5,025,774	58,021	129,680
3rd	5,171,767	4,985,568	57,557	128,643
4th	5,359,453	5,166,496	59,645	133,311
Peak Month	1,881,466	1,809,271	21,353	50,842
Peak Day	66,403	63,480	587	2,336

TABLE ES.3

BASELINE ESTIMATE IAD (Kg)

AIRCRAFT/CATEGORY	TOTAL	AIR CARRIER	AIR TAXI	GA
Annual	3,689,150	3,455,674	51,304	182,172
Quarterly				
1st	902,166	857,007	6,721	38,438
2nd	948,356	884,653	12,877	50,826
3rd	944,743	877,741	15,083	51,919
4th	893,885	836,273	16,623	40,989
Peak Month	323,060	309,787	2,301	10,972
Peak Day	32,677	31,670	95	912

TABLE ES.4

AIRLINE OPERATING PRACTICES-DCA NORTH OPERATIONS

AIRPORT-WASHINGTON NATIONAL NORTH OPERATION	AMERICAN	BRANIFF	DELTA	EASTERN	NORTHWEST	PAN AM	PIEDMONT	UNITED	U.S. AIR	TRANS WORLD
GATE OPERATION										
1. Use APU (with time and/or climate controls)	X	X	X	X	X	X	X	X	X	X
2. Use GPU		X	X		X	X		X		X
GATE DEPARTURE										
1. Hold at gate when delays long	X	X	X	X	X	X	X	X	X	X
2. Establish position in departure line	X	X	X	X	X	X	X	X	X	X
3. Start APU if not operating						X		X		X
4. Start engines at gate	No	No	No	No	No	No	No	No	No	No
5. Start engines during push-back		X		X	X	X		X	X	X
6. Start engines after push-back disconnect	X		X				X	X		
TAXI FOR TAKE-OFF										
1. Use all engines*	90%	90%	90%	75%	90%	90%	90%	90%	90%	90%
2. Use less than all engines	10%	10%	10%	25%	10%	10%	10%	10%	10%	10%
3. Shut down APU for taxi								X	X	
4. Shut down APU prior to take-off	X	X	X	X	X	X				X
5. Shut down APU when airborne							X			
DELAYS DURING DEPARTURE TAXI										
1. Taxi with less than all engines	X	X	X	X	X	X	X	X	X	X
2. Shut down APU for long delays	X		X	X			X	X	X	X
ARRIVAL OPERATIONS										
1. Use optimum runway exit	X	X	X	X	X	X	X	X	X	X
2. Use all engines*					50%	B-737	B-737	B-737		
3. Use less than all engines	X	X	X	X	50%	X	X	X	X	X
4. Start APU for gate arrival	X	X	X	X	X	X	X	X	X	X
MAINTENANCE AND OVERNIGHT										
1. Use APU	X				X		X			
2. Use GPU	X	X	X	X		X		X	X	X
3. Tow aircraft to and from gate	X	X	X	X	X	X	X	X	X	X
4. Taxi aircraft except for push-back	No	No	No	No	No	No	No	No	No	No

*B-737's, YS-11's and BE-99 aircraft taxi out and in with all engines operating.

X = Actual Procedure Used
No = Procedure Not Used

TABLE ES.5

AIRLINE OPERATING PRACTICES-DCA SOUTH OPERATIONS

AIRPORT-WASHINGTON NATIONAL SOUTH OPERATION	AMERICAN	BRANIFF	DELTA	EASTERN	NORTHWEST	PAN AM	PIEDMONT	UNITED	U.S. AIR	TRANS WORLD
GATE OPERATION										
1. Use APU (with time controls)	X	X	X	X	X	X	X	X	X	X
2. Use GPU		X	X		X	X		X		X
GATE DEPARTURE										
1. Hold at gate when delays long	X	X	X	X	X	X	X	X	X	X
2. Establish position in departure line	X	X	X	X	X	X	X	X	X	X
3. Start APU if not operating						X		X		X
4. Start engines at gate	No	No	No	No	No	No	No	No	No	No
5. Start engines during push-back	No	X	No	X	X	X	–	X	X	X
6. Start engines after disconnect	X		X				X	X		
TAXI FOR TAKE-OFF										
1. Use all engines*	90%	90%	90%	75%	90%	90%	90%	90%	90%	90%
2. Use less than all engines	10%	10%	10%	25%	10%	10%	10%	10%	10%	10%
3. Shut down APU for taxi								X	X	
4. Shut down APU prior to take-off	X	X	X	X	X	X		X		X
5. Shut down APU when airborne							X			
DELAYS DURING DEPARTURE TAXI										
1. Taxi with less than all engines	X	X	X	X	X	X	X	X	X	X
2. Shut down APU for long delays	X		X	X			X	X	X	X
ARRIVAL OPERATIONS										
1. Use optimum runway exit	X	X	X	X	X	X	X	X	X	X
2. Use all engines*					50%	B-737	B-737	B-737		
3. Use less than all engines	X	X	X	X	50%	X	X	X	X	X
4. Start APU for gate arrival	X	X	X	X	X	X	X	X	X	
MAINTENANCE AND OVERNIGHT										
1. Use APU	X				X		X			
2. Use GPU	X	X	X	X		X		X	X	X
3. Tow aircraft to and from gate	X	X	X	X	X	X	X	X	X	X
4. Taxi aircraft except for push-back	No	No	No	No	No	No	No	No	No	No

*B-737's, YS-11's and BE-99 aircraft taxi out and in with all engines operating.

X = Actual Procedure Used
No = Procedure Not Used

TABLE ES.6

AIRLINE OPERATING PRACTICES-IAD

AIRPORT-DULLES INTERNATIONAL	AMERICAN	BRANIFF	NORTHWEST	PAN AM	PIEDMONT	UNITED	U.S. AIR	TRANS WORLD	CONTINENTAL
GATE OPERATION									
1. Use APU (with time and/or climate controls)	X	X	X	X		X		X	X
2. Use GPU	X	X	X			X			X
GATE DEPARTURE									
1. Hold at gate when delays long	X	X	X	X	X	X		X	X
2. Establish position in departure line									
3. Start APU if not operating									
4. Start engines at gate	X	X	X	X	X	X		X	X
5. Start engines during push-back									
6. Start engines after disconnect									
TAXI FOR TAKE-OFF									
1. Use all engines	X	X	X	X		X		X	X
2. Use less than all engines			X	X		X		X	
3. Shut down APU for taxi				X		X			
4. Shut down APU prior to take-off									
5. Shut down APU when airborne									
DELAYS DURING DEPARTURE TAXI									
1. Taxi with less than all engines			X	X		X			
2. Shut down to APU for long delays									
ARRIVAL OPERATIONS									
1. Use optimum runway exit	X	X	X	X	X	X		X	X
2. Use all engines									
3. Use less than all engines	X	X	X	X		X		X	X
4. Start APU for gate arrival	X							X	X
MAINTENANCE AND OVERNIGHT									
1. Use APU									
2. Use GPU								X	
3. Tow aircraft to and from gate									
4. Taxi aircraft except for push-back									

*Does not operate from Dulles International Airport.

X = Actual Procedure Used
No = Procedure Not Used

The options evaluated by ORI, their fuel savings, implementation period, cost, social/economic impacts and rating category are shown in Tables ES.7 and ES.8. Categorization is a weighted rating given by ORI as defined in Table ES.9.

EVALUATION OF EXISTING COMPUTER MODELS

One of the objectives of the study effort was to determine the capability of using existing computer models to determine the fuel savings that could be realized were specified promising fuel conservation options implemented at other airports. An overview of the models evaluated by ORI is shown in Table ES.10. Both micro and macro type models were analyzed. In sum, it was concluded that none of the existing models is capable of performing all of the analysis included in this study effort.

Two models appeared to have the greatest potential for achieving the desired results: the SRI Taxi Model currently being developed under contract to FAA, Office of Environment and Energy and the ORI Aircraft Engine Pollution Model.

The SRI model is a micro model capable of determining the amount of time an aircraft spends in a particular mode. The addition of energy equations allows computation of fuel required during various ground operations procedures. Disadvantages to this model are the large number of parameters that must be entered into the computer that are aircraft/airport specific and the extraordinary time required to aggregate total operations.

The ORI model is a macro model which currently contains a large data base for the twenty-five largest (in terms of operations)air carrier airports in the United States. Using taxi data as an input parameter, it is possible to compute the fuel consumption and aggregate the data in terms of annual, quarterly, peak month and peak day operations.

CONCLUSIONS

The ORI investigation of promising fuel conservation procedures which are or could be implemented at DCA and IAD revealed that the FAA and the airlines are very conscious of fuel conservation and have published guidelines for the tower operators and pilots to follow in order to conserve fuel during ground operations.

Table ES 7

Summary of Implementation Considerations – DCA

Option	Fuel Savings (Kg/Yr)		Implementation Period	Cost ($)	Problems			Overall Impacts	Generally Applicable	Rating Category 2/
					Budgetary	Policy Related	Special 1/			
Procedural										
Computer Aided Paper Queue	7,887,000	Q	IT	Unknown	L&K	√	√	+	Yes	V
Manual Paper Queue	3,943,500	Q	ST	150,000	L	√	None	+	Yes	I
Pre-Taxi Engine Start Advisory	1,331,000	P	ST	50,000	L	√	None	+	Yes	V
Pre-Takeoff Engine Start Advisory	900,000	Q	ST	50,000	L	√	None	0	Yes	II
Maintenance of Unobstructed Taxi Paths	Minimal	T	ST	Minimal	None	None	None	0	Yes	II
Minimization of Start and Stop Actions	Minimal	T	ST	Minimal	None	None	√	0	Yes	II
Operational										
Less than all Engine Taxi	4,596,267	Σ	ST	0	None	None	√	+	Yes	I
Minimization of Pre-Taxi Engine Operation	665,500	P	ST	0	None	√	√	+	Yes	I
Favorable Engine Start Orientation	633,333	T	ST	0	None	√	√	+	Conditional	I
Most Direct Taxi Route	250,231	T	ST	0	None	None	√	–	Yes	V
Minimization of Last Engine Operation	900,000	Q	ST	0	None	√	√	0	Yes	II
Optimum Taxi Speed	212,500	T	ST	0	None	None	None	+	Yes	II
Aircraft Towing with Conventional Tow Vehicles	8,500,000	Σ	ST	3,000,000	K&L	√	√	+	Yes	IV
Aircraft Towing with Advanced Tow Vehicles	8,500,000	Σ	IT	3,000,000	K&L	√	√	+	Yes	IV
Airport Layout Changes										
Electrical Only Fixed Power Systems	2,700,000	G	ST	219,561/yr	K	√	√	+	Yes	V
Electrical & Oneumatic Fixed Power Systems	3,100,000	G	ST	823,362/yr	K	√	√	+	Yes	V
Taxiway Surface Improvements	950,000	T	IT	17,900,000	K	√	None	+	Conditional	III
High Speed Turnoff at Taxiway "I"	250,231	T	IT	1,500,000	K	√	√	–	Conditional	V
Special Holding Area	Unknown	Q	IT	2,750,000	K	√	None	+	Conditional	V
Extension of Runways 3-21 and 18-36	Unknown	Q	IT	Unknown	K	√	√	–	Conditional	IV

Legend: Activity Code
- Q = queuing
- P = pre-taxi, pushback and engine start
- T = taxi
- G = gate

Implementation Period
- ST = short term
- IT = intermediate term

Budgetary
- L = Labor
- K = Capital

1/ Special refers to problems which are airport specific

2/ See page ES-14 for definition

TABLE ES 8

Summary of Implementation Considerations – IAD

Option	Fuel Savings ($^{Kg}/_{Yr}$)	Implementation Period	Cost ($)	Problems: Budgetary	Problems: Policy Related	Problems: Special 1/	Overall Impacts	Generally Applicable	Rating Category 2/
Procedural									
Manual Paper Queue	400,000 Q	ST(IT)	Minimal	L(L&K)	✓	✓	+	Yes	II
Pre-Taxi Engine Start Advisory	Minimal P	ST	Minimal	L	✓	None	+	Yes	II
Pre Takeoff Engine Start Advisory	350,000 Q	ST	Minimal	L	✓	None	0	Yes	II
Maintenance of Unobstructed Taxi Paths	Minimal T	ST	Minimal	None	None	None	0	Yes	II
Minimization of Start and Stop Actions	Minimal T	ST	Minimal	None	None	✓	0	Yes	II
Operational									
Less than all Engine Taxi	1,733,618 Σ	ST	0	None	None	✓	+	Yes	I
Minimization of Pre Taxi Engine Operation	Minimal P	ST	0	None	✓	✓	+	Yes	II
Most Direct Taxi Route	Unknown T	ST	0	None	None	✓	–	Yes	II
Minimization of Last Engine Operation	350,000 Q	ST	0	None	✓	✓	0	Yes	II
Aircraft Towing with Conventional Tow Vehicles	1,780,917 Σ	ST	3,168,095/yr	K&L	✓	None	+	Conditional	IV
Aircraft Towing with Advanced Tow Vehicles	1,780,917 Σ	IT	1,089,079/yr	K&L	✓	None	+	Conditional	V
Optimum Taxi Speed	Unknown T	ST	0	None	None	None	+	Yes	II
Airport Layout Changes									
Electrical – Only Fixed Power Systems	750,000 G	ST	214,208/yr	K	✓	✓	+	Yes	V
Electrical and Pneumatic Fixed Power Systems	750,000 G	ST	642,624/yr	K	✓	✓	+	Yes	V
Taxiway Improvements	12,000 T	ST	Unknown	K	✓	None	+	Conditional	IV

Legend: Activity Code
- Q = queuing
- P = pre-taxi push back and engine start
- T = taxi
- G = gate

Implementation Period
- ST = short term
- IT = intermediate term

Budgetary
- L = Labor
- K = Capital

1/ Special refers to problems which are airport specific

2/ See page ES-14 for definition

TABLE ES.9

DECISION CATEGORY CLASSIFICATION CRITERIA

CATEGORY I

Options that can produce annual fuel savings amounting to at least 500,000 kilograms and are clearly cost effective.

CATEGORY II

Options that can produce annual fuel savings of less than 500,000 kilograms and are clearly cost effective.

CATEGORY III

Options that appear to be cost effective but involve substantial cost.

CATEGORY IV

Options that do not appear to be cost effective and for which implementation would be contingent upon considerations other than fuel conservation.

CATEGORY V

Options that require further study to determine benefits or to solve implementation problems.

TABLE ES.10

SUMMARY COMPARISON OF MODELS							
SOURCE AUTHOR YEAR TITLE	[illegible] 19[illegible] "AIRCRAFT TOWING FEASIBILITY STUDY"	ANL 1980 "AIRCRAFT EMISSIONS"	ORI 1980 "FAA ENGINE POLLUTION PROGRAM"	SPCAS 1980? "SIMULATION OF AIRPORT OPERATIONS"	SRI 1980 "AIRPORT TAXIWAY MODEL DESCRIPTIONS"	SRI 1979 "AIRPORT AIRSPACE DELAY MODEL"	TRANS SYSTEM [illegible] "GUIDANCE IN AIRSPACE AND LANDSIDE ENERGY"
USEFUL FOR:							
ENERGY	Y	N	M	M	M	M	Y
CAPACITY	In Ref. 9	N	N	Y	Y	Y	Y
AIR QUALITY	Y	Y	Y	M	M	M	M
NOISE	N	M	M	M	M	M	M
TIME	Y	N	N	Y	Y	Y	N
TRAFFIC MIX	Y	Y	Y	Y	Y	Y	Y
MODEL FORM:							
COMPUTER SIM	N	N	Data File	Y	Y	Y	Data File
COMPUTER SOL'N	N	N	N	N	N	N	N
CLOSED FORM	N	Y	N	N	N	N	Y
GRAPHICAL	N	N	N	N	N	N	Y
OUTPUT FORM:							
COMPUTER DATA	N	N	Y	Y	Y	Y	Y
EXPERIMENTAL DATA	N	Y	Y	N	N	N	Y
TABULATED RESULTS	Y	Y	Y	Y	Y	Y	Y
PARTICULAR AIRPORT	Y(DCA)	Y(DCA,IAD)	Y(DCA)	Y	Y	Y	Y
MODEL DESCRIPTION:							
COMPLETELY DESCRIBED	N	Y	Y	No Desc.	N	N	Y
COMPUTER LISTING	N	N/A	Y	N	N	N	N
EQUATIONS	N	Y	N/A	N	N	N	Y
GRAPHS	N	N	N	N	N	N	Y
COMMENTS	Directly Assumes Time Engines off	Closed Form, 2-Region, Standard Plums Analysis Extremely Poor Correlation with Data	Based on Time Allocation to Each Mode	Only sales Brochures Available Seems Comprehensive	Includes Optimal Taxi Path	Fast Running	Based on Other Simulations or on Trans Savings Estimates

TABLE ES.10 (Continued)

SUMMARY COMPARISON OF MODELS

SOURCE:					
AUTHOR	DOUGLAS	LOCKHEED	FAA	GELLMAN	MITRE
YEAR	1980	1980	1978	1977	1972
TITLE	"TOWING DC-9 ... LOGAN"	TOWING L- 1011 LOGAN"	"ENERGY CONSERVA-TION PRO-GRAM"	"AIRCRAFT TOWING"	"RUNWAY CAPACITY"
USEFUL FOR:					
ENERGY	N		Y	M	M
CAPACITY	N		N	M	Y
AIR QUALITY	N		Y	M	M
NOISE	N		Y	M	M
TIME	Y		N	Y	Y
TRAFFIC MIX	N		N	N	Y
MODEL FORM:					
COMPUTER SIM	N		N	?	Y
COMPUTER SOL'N	Y		N	N	N
CLOSED FORM	N		N	N	N
GRAPHICAL	N		N	N	N
OUTPUT FORM:					
COMPUTER DATA	N		Y	N	Y
EXPERIMENTAL DATA	Y		N	N	N
TABULATED RESULTS	Y		Y	Y	Y
PARTICULAR AIRPORT	N		N	N	Y
MODEL DESCRIPTION:					
COMPLETELY DESCRIBED	N		N	No Desc.	Y
COMPUTER LISTING	N		N	N	N
EQUATIONS	N		N	N	Y
GRAPHS	N		N	N	N
COMMENTS	Structural-Load Fatigue Model Only; include Effect of Taxiing Speed (pg 3-6 of Lockheed)		Included in Transystems Work	Highly Negative	In-flight Effects Only

TABLE ES.10 (Continued)

LEGEND

1. The model is indicated as useful for various studies according to whether a Y is listed (yes), an N (no), or an M (with modification).

2. Whether the model is a computer simulation, a computerized solution to mathematical equations, a closed-form mathematical solution, or a graphical solution is presented in the next section of the summary chart.

3. The form of the output can be in terms of computer data -- either a compendium of data or a tabulation of computed output; experimental data as used in developing an empirical model; tabulated results as typed for the report. If the output is suitable for use at a particular airport with known traffic pattern is also indicated. If DCA or IAD were considered in the particular report is also indicated.

4. The available model descriptions varied considerably, ranging from a Speas sales brochure to the MITRE mathematical equations. If the mathematics were presented, the description was judged complete (Y, for yes). If the description were in prose only, the description was judged as absent (N, for no). If vague words or no words were used to describe the model, "NO DESCRIPTION" was entered. A computer listing would be considered the most defined of all forms -- although they frequently contain disabling errors. If the model was described in terms of equations which were not necessarily used in the computer, a Y was entered on the line marked "EQUATIONS". If graphical output was the only form, so the model was described by graphs, a Y was entered on the next-to-last line.

Of the procedures currently being used by the airlines, taxiing with less than all engines saves the largest amount of fuel. The second most fuel conservative procedure is using the most direct route when taxiing to the gate after landing. Starting engines during pushback at DCA could save approximately 400,000 kg of fuel.

Holding at the gate to avoid airborne delays is a definite fuel savings procedure directly related to the length of the anticipated delay.

Fuel load planning was found to have an insignificant impact on fuel conservation during ground operations at DCA except when combined with less than all engine taxi. However, the cost of fuel, time saved by not refueling as well as the availability of fuel at the next destination may be major factors in an airline's decision whether or not to tanker.

Current fuel conservation practices and procedures were found to have either beneficial or neutral social/economic impacts.

Promising options which could conserve additional fuel revealed that implementing a computerized "sequencing system" to fairly and efficiently clear aircraft for take-off and thereby avoid excessive holding and queuing times is the most promising opportunity to conserve fuel at DCA. An improved manual system could be implemented in the near-term with a more sophisticated computer assisted system in the intermediate term. However, the low volume of traffic at IAD limits the total amount of fuel consumed and thus the amount of fuel which could be saved by reducing the amount of hold and queue time.

Taxiing with less than all engines operating at DCA would achieve large fuel savings while implementation costs would be minimal. An estimate that 4,596,267 kilograms would be saved was based upon the assumption that other actions to reduce delay were not implemented. Taxiing with one or more engines shut down at IAD revealed a potential annual fuel savings at over $1.7 million.

Improving aircraft orientation during pushback from the gate was estimated to result in an annual fuel savings of 633,333 kilograms or more,

assuming 20 seconds of idle power taxiing could be saved for each departure. Additional savings would accrue from reducing the operation of engines at above idle power during turning maneuvers. This option was not applicable at IAD.

A pretake-off advisory procedure to assist pilots anticipate an optimum engine start time was found to be clearly cost effective.

The costs of towing aircraft at DCA or IAD with advanced or conventional tow vehicles were estimated to be, respectively, 2 or 3 times the value of the fuel which would be saved. Other factors, such as congestion and high capacity utilization, make towing seem even less desirable.

Both electrical-only and combined electrical and pneumatic fixed power systems appear to be economically viable options for many of the airlines at DCA and IAD. These systems would not only save fuel but would also reduce the airline's ground crew and maintenance costs and improve the ramp environment.

Improving taxiway surfaces to reduce roughness and permit faster taxi speeds appears to be cost effective with respect to fuel saved over a period of years. This is particularly true when considered in terms of routine rehabilitation needs. The surfaces must be replaced from time to time in any event, and costs and benefits should be considered in terms of the decreased life and surfaces maintained for faster taxi speeds.

AREAS FOR ADDITIONAL STUDY

The ORI investigation of fuel conservation practices and procedures during ground operations at DCA and IAD identified a number of fuel conservation opportunity areas that warrant additional feasibility analyses in subsequent energy conservation studies. The objective of these studies would be to obtain knowledge that is not presently available and/or to explore implementation problems. These areas are:

- Evaluation of a computer aided ground traffic sequencing system (paper queue) for high density traffic airports.

An improved manual system could be developed and implemented in the near term. A computer assisted system could be implemented in the intermediate term. The costs and benefits as well as tower workload for such a system requires an in-depth analysis.

- Validation of algorithms used for computing fuel consumption during ground operations. The coefficient of rolling friction varies with the seasons for some surfaces (e.g., asphalt) and is not the same for all airports. Assumptions made for this report as well as the SRI taxi model need to be validated with actual fuel flow data.

- The optimum taxi speeds at an airport are affected by the accuracy of taxi speed estimates for taxiway segments. Since use of computers to evaluate traffic flow using variations in airport layout are sensitive to the speed with which an aircraft negotiates turns of various angles, and accelerates after stops, observations should be obtained for a representative sample of airports with varying layout situations.

- The FAA should promote workshops at the airport level with all effected parties (e.g., airlines, pilots, tower operators, ground personnel, etc.) to discuss and encourage fuel conservation.

- Electrical and pneueamtic fixed power systems have the potential for large fuel savings; however, the responsibility for installation of such systems requires further analysis. FAA should encourage installation of fixed power systems and offer assistance to interested parties with instructions and data base for interested parties to conduct benefit analysis for their particular airports.

I. INTRODUCTION

This report presents the results of an ORI, Inc. assessment of promising procedural, operational and airport layout changes that could be used to conserve fuel during ground operations at Washington National (DCA) and Dulles International (IAD) Airports. It is the final report of a five task investigation of energy conservation practices at the two airports and is based upon the findings reported in four previously completed tasks -- namely on-site investigations and development of a baseline estimate, investigation of current procedures and practices in use at DCA and IAD, an evaluation of current computer models which show promise for use in evaluating fuel conservation practices at airports of interest and an analysis promising procedural, operational, and/or airport layout changes that could reduce fuel consumption at DCA and IAD.

The ORI study is but one of several studies pertaining to energy conservation being conducted under the auspices of the Federal Aviation Administration. The other studies are investigating fuel savings that can be achieved in the air and in the operation of airport terminal facilities.

This report consists of nine sections. Section II presents an overview of the ORI data collection as well as the baseline estimate. Section III provides an overview of the actual and potential fuel savings available from current practices and procedures in use at DCA and IAD in addition to the associated socio-economic impacts. Section IV presents an overview of promising procedural, operational and/or

airport layout changes that could reduce fuel consumption at DCA and IAD. Section V considers the implementation of these procedures at DCA whereas Section VI considers their implementation at IAD. Section VII contains an overview of the current computer models which might have application for use in evaluating fuel conservation practices at any airport of interest. Section VIII presents the conclusions, while Section IX recommends energy conservation areas in which the FAA should explore in greater detail. Eleven appendicies are included which describe in greater detail material developed during the conduct of this study effort.

II. DATA COLLECTION AND BASELINE ESTIMATE

Data used for the ORI analysis of fuel conservation practices and procedures during ground operations that are or could be implemented by the government and by the airlines at Washington National (DCA) and Dulles International (IAD) airports were obtained through on-site investigations, discussions with airline and tower personnel as well as review of available literature. Procedures used for the collection and analysis of the data are summarized in this section. Details are provided in the Appendicies.

TAXI TIMES

An ORI project team consisting of ORI and Trans Systems Incorporated personnel observed and recorded outbound taxi and inbound taxi times during on-site visits to Dulles International (IAD) and Washington National (DCA) airports during the month of November 1980. Visits were scheduled to assure measurements would be made during both VFR and IFR meteorological conditions and during peak and non-peak hours during the day. Measurements were also made on both weekdays and on Saturdays and Sundays to determine the impact these factors would have on taxi times. In all, four visits were made to Dulles International and six visits were made to Washington National airports. Data was collected under the traffic and meteorological conditions as shown in Table 2.1.

In addition to the ORI effort, the FAA Technical Center was involved in a separate delay study at DCA. The ORI project team assisted the

TABLE 2.1

SCHEDULE OF VISITS TO DCA & IAD AIRPORTS AND ASSOCIATED TRAFFIC AND METEOROLOGICAL CONDITIONS

	MONDAY		TUESDAY	WEDNESDAY		FRIDAY			SATURDAY		SUNDAY		
	1600-1700	1700-1730	1100-1135	1000-1130		1300-1600	1600-1700	1700 1730	1330-1645	1645-1730	1100-1700		
Dulles International Airport													
IFR	X	X											
VFR			X	X		X	X	X	X	X	X		
Peak	X	X					X	X					
Non-Peak			X	X		X			X	X	X		
Day	X		X	X		X	X		X		X		
Night		X						X		X			
Predominant Runway	01	01	01	01		19	19	19	19	19	19		
				1130-1600	1600-1740	1325-1600	1600-1730	1730-1805	1410-1715		1255-1500	1500-1600	1600-1740
Washington National Airport													
IFR												X	
VFR				X	X	X	X	X	X		X		X
Peak					X		X	X					
Non-Peak				X		X			X		X	X	X
Day				X	X	X	X		X		X	X	X
Night								X					
Predominant Runway				01	36	18	18	18	36		18	18	18

FAA Technical Center collect data at DCA during the week of 17 November 1980. This data has been used to supplement the ORI data.

An attempt was made during the visits to collect data on all operations during the periods of observation; however, because of the large number of operations during peak hours, effort was directed towards assuring that a representative mix of traffic was recorded with especial attention given to collecting data on air carrier operations.

Data was recorded for both taxi-out and taxi-in operations by airline and aircraft type for each airport.

Once the raw data was collected, it was aggregated by airline and summarized by aircraft type in the following manner: by visibility conditions (IFR, VFR); by peak/non-peak activity periods; and by runway used. This enabled the project team to analyze the taxi times during ground operations under a variety of operational and meteorological conditions. Each of the times was then further disaggregated by the type of ground operations, e.g., taxiing, holding, waiting in queues and repositioning. Taxi routes used by each of the airlines were also recorded as well as the location that holding and queuing took place.

Detailed field data collection procedures used by the ORI-Trans Systems project team are contained in Appendix A. Also shown in this Appendix are the consolidated taxi times used for calculating the baseline estimates as well as the fuel savings that are or could be realized by using current and promising fuel conservation options.

OPERATIONS BY AIRCRAFT/AIRLINE TYPE

FAA Statistics on daily operations count at DCA and IAD provided the basic data source for the number of operations at these airports. The FAA publication FAA Air Traffic Activity provided a categorical breakdown of aircraft operations for fiscal year 1979 by air carrier, air taxi, and general aviation aircraft operations. These were then adjusted to calendar year 1979 by use of monthly statistical reports from FAA's Office of Management Systems, Data Systems Division (Table 2.2). These breakdowns of

TABLE 2.2

CY 1979 AIRCRAFT OPERATIONS AT IAD AND DCA AIRPORTS

AIRPORT/CATEGORY	TOTAL	AIR CARRIER	AIR TAXI	GA	MIL
DULLES INTL					
Itinerant	129258	52484	9143	64149	3482
Local	44786	-	-	39177	5609
Total	174044	52484	9143	103326	9091
WASHINGTON NATL					
Itinerant	352894	207112	48594	96793	395
Local	24	-	-	9	15
Total	352918	207112	48594	96802	410

categorical operations at each airport were then disaggregated for each selected airport by annual operations, by quarterly (seasonal variation), by peak month of the base year, and by the peak day of the base year.

Since air carrier and air taxi operations statistics obtained from various sources did not exactly total to the number of operations in the FAA Air Traffic Activity operations count, weighted percentages by aircraft type in each operator category at the selected airport were used to scale the detailed statistics by aircraft type to the FAA count.

Details on the methodology used by ORI to disaggregate the FAA operations data are shown in Appendix B.

FUEL CONSUMPTION RATES

Fuel consumption rates were determined for aircraft in current use at Dulles International and Washington National airports in the following manner.

1. Identification of those aircraft, by type and airline, with operations at IAD and DCA.
2. Based upon the airline and aircraft type, determination of applicable engine designation.
3. For each engine type identified, determination of fuel flow rate.
4. If information on a particular model of an engine series was not available, fuel flow rates for an engine in the series which most nearly matched the missing engines take-off thrust rating was used.

Matrixes similar to the operations tables, except that engine designations replaced the numbers of operations, were developed for the air carrier and air taxi aircraft (Tables 2.3 and 2.4) from information contained in the "Turbine-Engined Fleets of the World's Airlines 1979" Supplement to Volume 21, No. 3, 1979 Air World Survey. Since many of the commuter

TABLE 2.3

ENGINE DESIGNATION BY AIRLINE AND AIRCRAFT TYPE IAD

	American Airlines	Ahair Airlines	Braniff Airways	Continental Airlines	Delta Airlines	Eastern Airlines	Northwest Airlines	Ozark Airlines	Pan American	Piedmont Aviation	Republic Airlines	Seaboard World Air	Transworld Airlines	United Airlines	Western Airlines	British Airways	Air France	[illegible]
B727 100			JT-8D 7A	JT-8D-7/9			JT-8D 7A											
B727 100 C/QC			JT-8D 1/7A															
B727 100 C/QC	JT-8D 8		JT-8D 1/7A															
B727 200	JT-8D 8		JT-8D 8	JT-8D 8	JT-8D 15	JT-8D 7B 15	JT-8D 7A						JT-8D 15	JT-8D 7A/8	JT-8D 9/15			
B707 100B	JT-3D 3												JT-3D 3B					
B707 300																		
B707 300B	JT-3D 3								JT-3D 3B				JT-3D 3B					
B707 300C	JT-3D 3												JT-3D 3B					
B737 200										JT-8D 7/9				JT-8D 7A/8				
B747	JT-9D 3A						JT-9D-7		JT-9D 7A				JT-9D 3A			JT-9D 3A		
B747F							JT-9D-7F					JT-9D 7D		JT-9D 3				
B747SP									JT-9D 7A									
DC8 50			JT-3D 7		JT-3D 1									JT-3D 3B				
DC8 50F														JT-3D 3B				
DC8 61														JT-3D 3B				
DC8 62			JT-3D 3B											JT-3D 7				
DC9 10								JT-8D 7			JT-8D 7		JT-8D 5					
DC9 30					JT-8D 7A	JT-8D-7B		JT-8D 7			JT-8D 7/9/15							
DC9 80						JT-8D 17												
DC10 10	CF6-6D													CF6-6D				
DC10 40							JT-9D 20											
L1011					RB 211 22B	RB 211							RB 211 22B					
N262		Bastan VIC																
YS11										Dart 542 10B								
SSC Concorde			SNECMA Olympus 593													Olympus 593	Olympus 593	
VC10																Conway 550B		
IL62																		

Source FAA Airport Activity Statistics
Supplement to Volume 31 No 3 1979 Air World Survey
Turbine Engine Fleets of the World's Airlines 1979
1980 Annual Report Commuter Airline Industry

TABLE 2.4

ENGINE DESIGNATION BY AIRLINE AND AIRCRAFT TYPE DCA

	American Airlines	Altair Airlines	U.S. Air	Braniff Airways	Delta Airlines	Eastern Airlines	National Airlines	New Haven Airways*	Northwest Airlines	Piedmont Aviation	Air Florida	Republic Airlines**	Transworld Airlines	United Airlines	Empire Airlines	Western Airlines
B727-100			JT-8D-7						JT 8D 7A	JT 8D 7						
B727-100 C/QC																
B727 200	JT-8D 9		JT-8D 17	JT-8D 9/17R	JT 8D 15	JT-8D 7B 15	JT-8D 7		JT 8D 7A				JT 8D 15	JT 8D 7A 8		JT [illegible]
B737 200											JT 8D 7	JT 8D 7/9		JT-8D 7A/9		
DC9 10						JT-8D 7B						JT 8D 7	JT 8D 5			
DC9 30			JT-8D 7/9		JT-8D 7A	JT-8D 7B										
DC9 50						JT 8D 17						JT-8D 17				
N262		Bastan VIC														
YS11												Dart 542 10				
BH 99		PT 6A 20														
MO298																
BAC111 200			SPE - Y506 14DW													
PA Navaho																
PA Chieftain																
Embraer																
Swear Metro															TPE 331 303	

*Name changed to New Air
**Formed by the merger of North Central and Southern Airlines

Source: FAA Airport Activity Statistics
Supplement to Volume 31 No. 3 1978 Air World Survey Turbine Engined Fleets of the World's Airlines 1979
1980 Annual Report Commuter Airline Industry

airlines were not included in this data source, fleet mix data was verified in the 1980 Commuter Airline Industry Annual Report.

The primary source of data for determining fuel flow rates was the work previously completed by ORI as part of the FAA report Impact of Applying Alternate Aircraft Engine Emission Standards on Air Quality (FAA Report No. FAA-EE-79-14). This information was supplemented with material provided by the aircraft engine manufacturers (especially GE, P&WA and RR). The Rolls Royce data was updated by ORI based upon data submitted to FAA, Office of Environment and Energy and entitled The Variability of Production RB 211-524B-02 Engine Exhaust Emissions.

Table 2.5 lists the fuel flow rates for selected aircraft engines installed in aircraft which operate within the United States. The engines are listed in order of application - air carrier, air taxi, and general aviation. Fuel flow rates are shown for the engine manufacturer's idle, ICAO idle (7% F_{00}), approach (30% F_{00}), climbout (85% F_{00}) and take-off (100% F_{00}).

Further information pertaining to the determination of engine fuel flow rates is contained in Appendix C.

CALCULATIONS FOR BASELINE ESTIMATE

The baseline estimate of fuel consumed during aircraft ground operations at DCA and IAD airports was hand calculated. Simply put, fuel burn consisted of the fuel consumed during taxi-in and taxi-out plus fuel consumed to initiate aircraft roll after coming to a complete stop. No attempt was made to consider fuel saving options (e.g., shut down of engines, use of APU's etc.) for the baseline estimate.

BASELINE ESTIMATE

The baseline estimates for 1979 at DCA and IAD are shown in Tables 2.6 and 2.7.

TABLE 2.5

FUEL FLOW RATES

ENGINE	IDLE (% F_{oo})	7% F_{oo}	30% F_{oo}	85% F_{oo}	100% F_{oo}	SOURCE
			W_f (kg/hr)			
JT 3D 7	458 (4.7)	NA	1334	3629	4468	P&WA
JT 8D 9	461 (6.0)	475	1072	3044	3744	P&WA
JT 8D 17	519 (6.4)	529	1275	3588	4481	P&WA
JT 9D 7	760 (6.4)	790	2109	6078	7303	P&WA
JT 9D 70	744 (5.6)	853	2449	7199	8791	P&WA
CF 6 6D	466 (3.0)	677	1728	5207	6304	GE
CF 6 50C	549 (3.3)	764	2392	7032	8552	GE
CFM 56*	402 (6.0)	410	1010	2815	3380	GE
RB211-22B	627 (4.6)	791.28	2001.6	5540.4	6706.8	RR
TFE 731-2-2B	NA	86.4	241.2	622.8	738	AiResearch
TFE 731-3	NA	93.6	259.2	669.6	810	AiResearch
CF 6-32*	NA	626.4	1555.2	4701.6	5734.8	GE (based on CF 6-6 corrected to CF 6-32 cycles)
CF 6-45	NA	727.2	2178	6372	7653.6	GE (based on CF 6-50 corrected to CF 6-45 cycles)
CF 34	173 (6.4)	193.68	432	1177.2	1418.4	GE (based on TF 34 corrected to CF 34 cycles)
JT 8D-209	NA	544.32	1265.4	3510.72	4354.56	P&WA
JT 9D-7F (MOD V)	NA	788.4	2245.32	6350.4	7801.92	P&WA
JT 15D	NA	82.8	183.6	446.4	532.8	P&WA
JT 15D-4	NA	77.76	212.4	514.8	610.92	P&WA
M 45H-01	NA	190.8	525.6	1497.6	1792.8	RR
RB 211-524B2	661 (NA)	979.2	2494.8	6980.4	8578.8	RR
RB 211-535	544 (NA)	662.4	1944	5328	6573.6	RR
SPEY M 511	401 (NA)	428.4	1004.4	2613.6	3200.4	RR
SPEY MK 555	341 (NA)	414	799.2	2120.4	2592	RR
OLYMPUS 593 M610	NA	2466(15%) 1515.6	4215.6 (34%)	8384.4 (65%)	22914	RR
ALF 502D	168 (6.2)	NA	354	1005	1205	EPA (Pace Report)
ALF 502L	173 (5.3)	NA	478	1185	1416	EPA (Pace Report)
CJ 610-2C	231.3 (NA)	NA	464.9	1102.0	1261.0	EPA (Pace Report)
RB 401-06	149.7 (NA)	NA	351.5	966.2	1089	EPA (Pace Report)
TPE 331-2	47.6 (NA)	NA	99.8	168.7	183.7	EPA (Pace Report)
PT 6-27	52.16 (NA)	NA	97.52	181.4	192.8	EPA (Pace Report)
250 B 17B	28.58 (NA)	NA	38.56	111.1	120.2	EPA (Pace Report)
501 D 22A	276.7 (NA)	NA	517.1	997	1078	EPA (Pace Report)
DART R DA 7	186.4 (NA)	NA	292.6	566.1	639.1	EPA (Pace Report)
RR TYNE	280.8 (NA)	NA	496.7	992.5	1076	EPA (Pace Report)
IO 520F	13.6 (NA)	NA	38.1	67.1	90.7	EPA (Pace Report)
T SIO-520E	11.8 (NA)	NA	40.8	77.1	97.1	EPA (Pace Report)
IO-540E	11.8 (NA)	NA	24.5	58.1	78.9	EPA (Pace Report)
T SIO-360E	18.1 (NA)	NA	54.4	107	136.1	EPA (Pace Report)
0470 U	10.9 (NA)	NA	29.5	54.4	68	EPA (Pace Report)
JT 3C	543 (NA)	NA	1867	3860	4619	EPA AP 42
JT 4A	630 (NA)	NA	2719	5927	7036	EPA AP 42
CJ 805	454 (NA)	NA	1713	3760	4518	EPA AP 42
T 56-A15	224 (NA)	NA	520	992	1085	EPA AP 42
T 56-A7	249 (NA)	NA	478	865	943	EPA AP 42
O-200	3.48 (NA)	NA	9.66	22	22	EPA AP 42
O-320	5.9 (NA)	NA	10.5	28.8	29.8	EPA AP 42

*Current Development Status

TABLE 2.6

BASELINE ESTIMATE DCA (Kg)

AIRCRAFT/CATEGORY	TOTAL	AIR CARRIER	AIR TAXI	GA
Annual	20,853,901	20,103,097	232,083	518,721
Quarterly				
1st	5,109,206	4,925,259	56,860	127,087
2nd	5,213,475	5,025,774	58,021	129,680
3rd	5,171,767	4,985,568	57,557	128,643
4th	5,359,453	5,166,496	59,645	133,311
Peak Month	1,881,466	1,809,271	21,353	50,842
Peak Day	66,403	63,480	587	2,336

TABLE 2.7

BASELINE ESTIMATE IAD (Kg)

AIRCRAFT/CATEGORY	TOTAL	AIR CARRIER	AIR TAXI	GA
Annual	3,689,150	3,455,674	51,304	182,172
Quarterly				
1st	902,166	857,007	6,721	38,438
2nd	948,356	884,653	12,877	50,826
3rd	944,743	877,741	15,083	51,919
4th	893,885	836,273	16,623	40,989
Peak Month	323,060	309,787	2,301	10,972
Peak Day	32,677	31,670	95	912

III. CURRENT FUEL CONSERVATION OPTIONS

Fuel conservation options applicable to aircraft operating at DCA and IAD airports include:

- Starting engines during pushback
- Taxiing out or in with one or more engines shutdown
- Planning landing roll turn-off and taxiing to the terminal with the most direct routing
- Gate hold procedures
- Fuel load planning practices.

This subsection provides a discussion of each option.

STARTING ENGINES DURING PUSHBACK

Many pilots start aircraft engines durirg pushback from the gate to enable them to be ready to taxi as soon as the pushback vehicles have been disconnected. Although additional time on the ground results if the pilot waits until after disconnect to start aircraft engines, starting engines during pushback will not affect the distance the aircraft must taxi nor the time needed to taxi from the pushback location to the departure runway. Assuming that the same amount of fuel would be burned by the engines in either instance, fuel savings would result from reducing the time the APU's would be operating.

APU's are operated to provide power needed when the engines are not running and the aircraft is not connected to a ground power unit. Discussions with pilots and tower personnel reveal little difference in the time it takes to obtain clearance to taxi whether the engines are started during pushback or whether they are started after pushback. This is because clearance to taxi is requested after the engines are started and stabilized and the aircraft is ready to roll.

TAXIING OUT OR IN WITH ONE OR MORE ENGINES SHUTDOWN

Reducing the number of operating engines on an aircraft during taxi is a viable fuel conservation option because the thrust from engines operating at idle power settings in most instances is more than the thrust needed to maintain an established taxi speed. (Aircraft brakes are used to control taxi speed.) In those instances where additional taxi thrust is required to compensate for a shutdown engine, the fuel consumption is still less than that which would be required were all the engines operating at idle power.

This option also conserves fuel while the aircraft is stopped; however, it does not apply during the period needed to unstick and accelerate the aircraft from rest. This is because pilots increase thrust on the operating engines to the amount needed to produce the desired acceleration. The same amount of total thrust and approximately the same amount of fuel is needed for each unstick and acceleration event irrespective of the number of operating engines.

Aircraft acceleration rates to begin taxi activity were not observed but were estimated to be 1 to 2 feet per second per second (ft/sec^2) with an average generally less than 1.5 ft/sec^2 (this is equal to 0.0462g where "g" is the acceleration of gravity (32.2 ft/sec^2). A period of 10 seconds was assumed to reach a taxi speed of 15 feet per second (10 MPH). A 5 to 10 second period was consistent with pilot estimates of the length of time additional thrust is applied to initiate aircraft roll and accelerate at Washington National Airport. Higher acceleration rates would be expected at airports where faster taxi speeds are acceptable, and lower rates when acceleration is to slower speeds.

Less than all engine taxi operations did not save fuel for periods of about 5 to 10 seconds for each start and stop action. In addition, the less than all engine taxi operating option did not apply to the last 2 minutes, approximately, before take-off when all engines must be operating.

Since nose wheel steering and engine thrust are used for directional control during taxi operations, aircraft with engines located close to the fuselage are easier to control with less than all engines operating than those with engines located along the wings. Less than all engine taxi is not practical when thrust from remaining engines produces a significant turning force and when runway surfaces are slippery.

PLANNING LANDING ROLL, TURN-OFF AND TAXIING TO THE TERMINAL WITH THE MOST DIRECT ROUTING

Planning the landing roll to permit exit from the runway at a location which would enable the most direct route for taxi to the gate conserves fuel. However, a less direct route would be the better choice if taxi time would be reduced by avoiding a control point and/or a congested area. The most direct route option translates into having a runway exit choice in most instances. The optimum choice for those gates located nearest the approach end of the runway would be to touch-down early and turn-off at the first exit for which a turn can be safely executed. This allows the aircraft to clear the active runway as soon as possible for following traffic. An added benefit is the shorter distance the aircraft has to taxi back to reach its gate. If the gate is beyond the turn-off point, the aircraft could extend its touchdown point and exit farther down the field.

The direct routing taxi option would be counter productive if the pilot uses more power (reverse thrust) to stop sooner.

GATE HOLD PROCEDURES

Holding an aircraft at a gate, with engines not operating to avoid known airborne or destination delays, reduces the total amount of fuel needed for the aircraft to hold over a fix at its destination. However, the aircraft can not use this option if the gate is needed by an arriving aircraft.

If the gate is needed, the aircraft may hold in a special area. It is less effective than holding at a gate because APU's must be operated while aircraft remain in the special holding area.

Holding options at the gate in order to use less aviation fuel involve use of more efficient power sources and/or reduced use of power. For example, the range of acceptable cabin temperatures could be expanded thereby reducing the fuel (power) required to heat or cool aircraft interiors. More efficient power sources, however, could involve major costs for capital investment.

Aircraft need energy while at a gate to operate electrical equipment to heat and cool aircraft interiors, and to start engines. This energy can be provided by Fixed Power Systems (FPS) at each gate position, by ground power units (GPU's), and by auxiliary power units (APU's) on aircraft. Energy for gate activities can also be provided by operating an aircraft engine. APU's and an operating engine provide pneumatic power needed for heating and cooling and to start an engine, as well as the electrical energy. GPU's satisfy only the electrical energy demand and must be supplemented by another power source when pneumatic power is needed. Air start units are used on jet aircraft of the B-707 and DC-8 vintage to start engines and to heat or cool aircraft interiors. The older and smaller (commuter type) aircraft start an engine with a battery and use the engine power to satisfy energy needs at the gate.

Fixed power systems can be installed at airport gate positions with connections to provide pneumatic as well as electrical energy needed by aircraft. Electrical energy for this power source can be generated remotely with any form of fuel or energy such as coal or hydroelectric power. Fixed power systems are being installed at an increasing number of airports. They are economically advantageous and represent an option to reduce use of fuel derived from oil. A U.S. Air installation with 23 gate positions at Greater Pittsburgh International Airport, for example, is expected to pay

for itself in approximately 2 years.[1] A few such systems have been installed at Washington National and Dulles International Airports.[2]

FUEL LOAD PLANNING PRACTICES

Fuel load planning was examined with respect to the impact of tankering on ground operations. (The practice of carrying more fuel than needed is called tankering). Additional fuel is used in the air when more fuel is carried than needed for a given flight simply because of the extra weight. The extra fuel might be carried for one or more reasons such as:

- Fuel costs are less at one airport than at the next.
- Time on the ground at the next stop can be reduced if refueling at that stop can be avoided.
- Fuel loads exceeding FAA and Company reserve requirements are desired by the pilot.

The cost of carrying more fuel than needed is a matter of concern to airline management and fuel loads are being controlled. Northwest Orient Airlines, for example, estimates that 6% of the extra fuel on a 1,000 mile flight is consumed simply because the aircraft is heavier, and that 25% of it is consumed on a 3,000 mile flight. (Reference: Northwest Orient Airlines Flight Standards Bulletin of 16 May 1980). Fuel load planning and control is a matter of economic as well as safety concern to airline management.

A tankering action could affect fuel use on the ground if the aircraft is required to stay on the ground longer to refuel. It could also affect fuel use on the ground if more fuel is needed to taxi because the aircraft is heavier. In most instances, more fuel could be loaded without increasing aircraft time on the ground. In most instances, no additional fuel is needed for aircraft taxi operation because the thrust at idle power

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[1]November 7, 1980 News Release by U.S. Air.

[2]TWA and UA have electrical power in the ground at some IAD gates. TWA and NW have electrical power at DCA.

is more than adequate for taxi. However, if this practice is combined with less than all engine taxi procedures, greater thrust on the remaining engines would be required and the total potential fuel savings less. Otherwise, fuel load planning does not represent a significant conservation option for aircraft operations on the ground.

AIRLINE OPERATION PRACTICES

Airline personnel at Washington National and Dulles International Airports were interviewed to develop a general perspective concerning operating practices being used to conserve fuel. All of the airlines were found to be devoting significant attention to conservation of fuel during ground operations as well as in the air. Significant differences in operating practices were mainly associated with equipment availability and characteristics. B-737 pilots, for example, rarely taxi in or out on one engine because thrust from a single operating engine produces undesirable steering forces. Pilots operating another two engine aircraft, the DC-9, do taxi on a single engine because DC-9 engines are located much nearer the aircraft center line and single engine thrust does not produce undesirable steering forces. Tables 3.1 through 3.3 summarize the results of the survey of the air carriers which operate at DCA and IAD airports to determine which of the fuel conservation measures they use. Different techniques are used for North versus South operations at DCA and are so reported. Detailed formation for each airline is contained in Appendix D. Each fuel saving procedure was evaluated by airline/aircraft type to determine the actual and potential fuel savings. Sample fuel consumption analyses are contained in Appendix E.

Tables 3.4 and 3.5 present the fuel savings by airlines and in aggr- ate for each procedure currently being employed at DCA and IAD respe-. vely. The data for actual savings when starting engines during pushback appeared inconsistent with the potential savings for this procedure. Starting engines during pushback was not applicable to IAD. In addition, fuel savings from holding at the gate are based upon the amount of time that would be avoided holding over a fix. These savings are shown in kg saved per minute.

TABLE 3.1

AIRLINE OPERATING PRACTICES-DCA NORTH OPERATIONS

AIRPORT WASHINGTON NATIONAL NORTH OPERATION	AMERICAN	BRANIFF	DELTA	EASTERN	NORTHWEST	PAN AM	PIEDMONT	UNITED	U.S. AIR	TRANS WORLD
GATE OPERATION										
1. Use APU (with time and/or climate controls)	X	X	X	X	X	X	X	X	X	X
2. Use GPU		X	X		X	X		X		X
GATE DEPARTURE										
1. Hold at gate when delays long	X	X	X	X	X	X	X	X	X	X
2. Establish position in departure line	X	X	X	X	X	X	X	X	X	X
3. Start APU if not operating						X		X		X
4. Start engines at gate	No	No	No	No	No	No	No	No	No	No
5. Start engines during push-back		X		X	X	X		X	X	X
6. Start engines after push-back disconnect	X		X				X	X		
TAXI FOR TAKE-OFF										
1. Use all engines*	90%	90%	90%	75%	90%	90%	90%	90%	90%	90%
2. Use less than all engines	10%	10%	10%	25%	10%	10%	10%	10%	10%	10%
3. Shut down APU for taxi								X	X	
4. Shut down APU prior to take-off	X	X	X	X	X	X				X
5. Shut down APU when airborne							X			
DELAYS DURING DEPARTURE TAXI										
1. Taxi with less than all engines	X	X	X	X	X	X	X	X	X	X
2. Shut down APU for long delays	X		X	X			X	X	X	X
ARRIVAL OPERATIONS										
1. Use optimum runway exit	X	X	X	X	X	X	X	X	X	X
2. Use all engines*					50%	B-737	B-737	B-737		
3. Use less than all engines	X	X	X	X	50%	X	X	X	X	X
4. Start APU for gate arrival	X	X	X	X	X	X	X	X	X	X
MAINTENANCE AND OVERNIGHT										
1. Use APU	X				X		X			
2. Use GPU	X	X	X	X		X		X	X	X
3. Tow aircraft to and from gate	X	X	X	X	X	X	X	X	X	X
4. Taxi aircraft except for push-back	No	No	No	No	No	No	No	No	No	No

*B-737's, YS-11's and BE-99 aircraft taxi out and in with all engines operating.

X = Actual Procedure Used
No = Procedure Not Used

TABLE 3.2

AIRLINE OPERATING PRACTICES-DCA SOUTH OPERATIONS

AIRPORT-WASHINGTON NATIONAL SOUTH OPERATION	AMERICAN	BRANIFF	DELTA	EASTERN	NORTHWEST	PAN AM	PIEDMONT	UNITED	U.S. AIR	TRANS WORLD
<u>GATE OPERATION</u>										
1. Use APU (with Time Controls)	X	X	X	X	X	X	X	X	X	X
2. Use GPU		X	X		X	X		X		X
<u>GATE DEPARTURE</u>										
1. Hold at gate when delays long	X	X	X	X	X	X	X	X	X	X
2. Establish position in departure line	X	X	X	X	X	X	X	X	X	X
3. Start APU if not operating						X		X		X
4. Start engines at gate	No	No	No	No	No	No	No	No	No	No
5. Start engines during push-back	No	X	No	X	X	X	–	X	X	X
6. Start engines after disconnect	X		X				X	X		
<u>TAXI FOR TAKE-OFF</u>										
1. Use all engines*	90%	90%	90%	75%	90%	90%	90%	90%	90%	90%
2. Use less than all engines	10%	10%	10%	25%	10%	10%	10%	10%	10%	10%
3. Shut down APU for taxi								X	X	
4. Shut down APU prior to take-off	X	X	X	X	X	X		X		X
5. Shut down APU when airborne							X			
<u>DELAYS DURING DEPARTURE TAXI</u>										
1. Taxi with less than all engines	X	X	X	X	X	X	X	X	X	X
2. Shut down APU for long delays	X		X	X			X	X	X	X
<u>ARRIVAL OPERATIONS</u>										
1. Use optimum runway exit	X	X	X	X	X	X	X	X	X	X
2. Use all engines*					50%	B-737	B-737	B-737		
3. Use less than all engines	X	X	X	X	50%	X	X	X	X	X
4. Start APU for gate arrival	X	X	X	X	X	X	X	X	X	
<u>MAINTENANCE AND OVERNIGHT</u>										
1. Use APU	X				X		X			
2. Use GPU	X	X	X	X		X		X	X	X
3. Tow aircraft to and from gate	X	X	X	X	X	X	X	X	X	X
4. Taxi aircraft except for push-back	No	No	No	No	No	No	No	No	No	No

*B-737's, YS-11's and BE-99 aircraft taxi out and in with all engines operating.

X = Actual Procedure Used
No = Procedure Not Used

TABLE 3.3

AIRLINE OPERATING PRACTICES-IAD

AIRPORT-DULLES INTERNATIONAL	AMERICAN	BRANIFF	NORTHWEST	PAN AM	PIEDMONT	UNITED	U.S. AIR	TRANS WORLD	CONTINENTAL
GATE OPERATION									
1. Use APU (with time and/or climate controls)	X	X	X	X		X		X	X
2. Use GPU	X	X	X			X			X
GATE DEPARTURE									
1. Hold at gate when delays long	X	X	X	X	X	X		X	X
2. Establish position in departure line									
3. Start APU if not operating									
4. Start engines at gate	X	X	X	X	X	X		X	X
5. Start engines during push-back									
6. Start engines after disconnect									
TAXI FOR TAKE-OFF									
1. Use all engines	X	X	X	X		X		X	X
2. Use less than all engines			X	X		X		X	
3. Shut down APU for taxi				X		X			
4. Shut down APU prior to take-off									
5. Shut down APU when airborne									
DELAYS DURING DEPARTURE TAXI									
1. Taxi with less than all engines			X	X		X			
2. Shut down to APU for long delays									
ARRIVAL OPERATIONS									
1. Use optimum runway exit	X	X	X	X	X	X		X	X
2. Use all engines									
3. Use less than all engines	X	X	X	X		X		X	X
4. Start APU for gate arrival	X							X	X
MAINTENANCE AND OVERNIGHT									
1. Use APU									
2. Use GPU								X	
3. Tow aircraft to and from gate									
4. Taxi aircraft except for push-back									

*Does not operate from Dulles International Airport.

X = Actual Procedure Used
No = Procedure Not Used

TABLE 3.4

FUEL SAVINGS BY PROCEDURE - DCA

PROCEDURES \ AIRLINE	AIR FLORIDA	AMERICAN	BRANIFF	DELTA	EASTERN	NATIONAL	NORTH CENTRAL	NORTHWEST	PIEDMONT	REPUBLIC	TRANS WORLD	UNITED	US AIR	WESTERN	TOTAL
Start Engines During Pushback															
Potential[1/] (kg/yr)	1,599	39,231	16,815	25,150	104,721	22,145	38	43,648	27,951	1,088	28,399	30,548	38,273	1,409	381,015
Taxi Using Less Than All Engines															
Actual (kg/yr)	1,710	156,898	45,490	77,264	512,252	68,878	141,420	113	41,632	1,772	130,926	52,888	71,818[2/]	16,218	1,319,273
Potential (kg/yr)	21,337	509,753	212,601	310,319	1,370,755	211,932	317,514	363	499,461	8,687	421,657	499,547	203,442[2/]	9,399	4,596,267
Use Direct Routing															
Potential[3/] (kg/yr)															250,231
Use Gate Hold Procedures															
Potential[4/]		B 727		BAC 111		DC 9		B 737							
APU (kg/min)		22.4		12.7		14.7		16.4							
GPU (kg/min)		23.02		13.32		15.32		17.22							
Fuel Load Planning[5/]															

[1/] Using data collected during Task 1, there is actually more fuel consumed when engines are started during pushback.

[2/] Does not include BAC 111 a/c.

[3/] Actual fuel savings cannot be determined - Potential savings based upon elimination of instances aircraft landed long.

[4/] Savings shown by a/c type if a/c remain at gate on GPU or in holding area on APU rather than engines running.

[5/] Savings are considered insignificant.

TABLE 3.5

FUEL SAVINGS BY PROCEDURE - IAD

PROCEDURE \ AIRLINE	AIR FRANCE	AMERICAN	BRANIFF	CONTINENTAL	DELTA	EASTERN	NORTHWEST	OZARK	PAN AMERICAN	PIEDMONT	REPUBLIC	TRANS WORLD	UNITED	BRITISH AIRWAYS	TOTAL
Start Engines During Pushback[1/]															
Taxi Using Less Than All Engines															
Actual (kg/yr)	51,045	103,072	120,511	25,700	13,182	52,407	59,721	13,014	128,621	73	12,596	73,697	106,515	64,317	824,471
Potential (kg/yr)	93,194	252,072	252,749	56,583	27,048	109,003	120,216	25,340	219,537	1,345	22,796	224,264	223,084	117,782	1,745,049
Use Direct Route[2/]															
Gate Hold Procedure Gate Hold Procedures[1/]															
Fuel Load Planning[1/]															

[1/] Not applicable at IAD

[2/] Light traffic and dual runways allow aircraft to use the most direct route to the parking apron.

IMPACT OF ENERGY CONSERVATION MEASURES ON SOCIAL/ECONOMIC CONSIDERATIONS

Each of the fuel savings procedures implemented at DCA and IAD airports were examined to determine the possible effects of implementation on:

- Safety
- Airport capacity
- Passenger convenience
- Noise and Air Quality levels
- Airline/Airport revenues.

Where possible, these social/economic elements were quantified. For example, the reduction in emissions that could be realized from taxiing with less than all engines operating were determined. In other instances, the analysis was subjective in nature, e.g., the impact of implementation on safety. Airline revenues were computed based upon the average fuel price per gallon in 1979. With the projected increase in the price of fuel, these savings will become much more dramatic. A summary of the impact of each of these factors is shown in Table 3.6. Details of the ORI analysis are contained in Appendix G.

TABLE 3.6

IMPACT OF ENERGY CONSERVATION MEASURES ON SOCIAL/ECONOMIC MATTERS

CONSERVATION STRATEGY	SAFETY		NOISE		EMISSIONS		AIRPORT CAPACITY		AIRLINE COST REVENUES		PASSENGER CONVENIENCE	
	DCA	IAD	DCA	IAD	DCA	IAD	DCA	IAD	DCA	IAD	DCA	IAD
Start Engines During Pushback*	0	N/A	0	N/A	+	N/A	0	N/A	+	N/A	0	N/A
Taxi Using Less Than All Engines												
Taxi In (Arrival)	0	0	+	+	+	+	0	0	+	+	0	0
Taxi Out (Departure)	-	-	+	+	+	+	0	0	+	+	0	0
Use Direct Route	0	0	+	+	+	+	-	0	+	+	0	0
Hold for Departure Delay												
At Gate	0	0	+	+	+	+	0	0	+	+	+	+
At Special Location	0	N/A	+	N/A	+	N/A	0	N/A	+	N/A	0	N/A
Fuel Load Planning	0	0	0	0	0	0	0	0	0	0	0	0

+ = Beneficial Effect
0 = Neutral Net Effect or Not Perceptible
- = Potential Deleterious Effect
N/A = Not Applicable

IV. PROMISING OPTIONS

GENERAL

It is convenient to consider options to conserve fuel during aircraft operations on airports in terms of implementing authority as well as operating activities. Some options can be implemented by airline managers and pilots. These are called operational options. Another family of options involve traffic management. These are called procedural options. They can be implemented by the FAA. The third family of options involve changes in airport design and facilities. These are called airport layout options and can be implemented by airport management. DCA and IAD are managed by the FAA.

Procedural, operational and airport layout options to conserve fuel interact to the extent that each affects the same delay. For example, procedural steps to reduce delay on the airport also reduce the amount of fuel that can be saved by taxiing with less than all engines operating. The procedural steps reduce the total amount of fuel used by operating engines and also reduce the benefit that can be achieved by shutting down one engine.

Promising options are the procedural, operational and airport layout changes that can be implemented and which can produce significant savings. Implementing difficulty is a factor to be considered. An easily

implemented option would be a promising option even though fuel savings might be less than another that is difficult to implement.

PROCEDURAL OPTIONS

Procedural options to improve fuel conservation on airports are actions that can be taken by controllers to help pilots reduce engine operating time. These opportunities occur in connection with two traffic management activities:

- Departure Sequences: Queues occur when aircraft form lines while waiting for permission to take-off or to cross control points. Fuel can be saved if aircraft can be held at the gate or at a special holding area to avoid queuing. Paper queues represent a sequence management procedure to minimize waiting in queues and to conserve fuel.

- Permission to Taxi: Engines are operating and aircraft are ready to taxi when permission to taxi is requested. Starting engines too soon wastes fuel. A procedure to help pilots anticipate clearance to taxi would help pilots minimize engine operation and fuel use before the taxi activity can be commenced. Procedures advising pilots of an optimum engine start time for taxi are logically a part of the paper queue procedure. However, an engine start advisory practice is also an independent option because the engine start and taxi procedure can be implemented to save fuel even though a paper queue procedure is not used.

- Three independent procedural options produce small but useful fuel savings. These options are easy to implement, used to some degree now, and are independent of other procedural actions. They are as follows:

    - Minimize start and stop actions.

    - Maintain unobstructed engine start areas and taxi paths.

- Provide a pre-take-off alert to help pilots know when to start the last engine for take-off.

Traffic procedures focus attention on operating safety and capacity. Procedures for fuel conservation add a new element because lines of aircraft waiting to take-off waste fuel. Procedural options to conserve fuel are promising to the extent that airport capacity is not significantly reduced by the procedure.

One of the problems associated with paper queues involves the method used to establish positions in the line. Physical queues are preferred because they demonstrate that aircraft are actually ready to taxi or take-off. Positions in a paper queue can be requested before aircraft are ready. Paper queues complicate the scramble to be the first of several flights scheduled for the same departure time because of the need to impose an administrative control over an intensely competitive activity. Administrative solutions include the following methods for resolving sequencing problems:

- The establishment of airport specific procedures by airlines and controllers for determining positions in queuing activities.
- The establishment of position sequencing in queues for designated periods by a lottery system.
- The use of competitive bidding to allocate favored time slots.
- Continuing the present system for requesting and receiving permission to cross control points or to take-off but imposing some time limitation and/or penalty for misrepresenting anticipated readiness.

OPERATIONAL OPTIONS

Operational options are actions that can be taken by airline managers and pilots. They include the following

- Holding at the gate for expected delays.

- Provide aircraft towing services.
- Pushing back to a favorable engine start location and orienting aircraft toward the direction it will taxi.
- Minimizing pre-taxi engine operation.
- Taxiing in and out for arrival and departure with less than all engines operating.
- Using the most direct taxi route.
- Minimizing start and stop actions during taxi.
- Using maximum prudent taxi speed without increasing power for taxi.
- Minimizing last engine operating time.
- Establishing multiple gate use exchange agreements to enable increased use of existing gates for gate hold situations.

Each of these options can and are being implemented at the discretion of airline managers and pilots. Each option can be more fully used, and each saves fuel, but the most important of these is taxiing with less than all engines.

AIRPORT LAYOUT OPTIONS

Airport layout options are the changes in airport design and facilities that can be implemented to save fuel. Each of the following actions represents airport layout options to conserve fuel:

- Improve taxiways
  - Replace rough and uneven surfaces
  - Construct additional taxiways
  - Construct high speed turnoffs.
- Construct special holding areas
- Extend runways
- Construct new runways

- Provide additional gates
- Add conventional gates
- Add remote gates with mobile lounges
- Provide fixed power at gates.

All of the options except additional gates and fixed power systems are delay associated, and their benefits are reduced by any other actions that reduce delay.

The following two sections present the results of an analysis of each of the above procedures (practices) as they apply to DCA (Section IV) and IAD (Section V).

V. WASHINGTON NATIONAL AIRPORT

This section presents the procedural and operational practices and options applicable to Washington National Airport (DCA).

PROCEDURAL OPTIONS

Paper Queue

The paper queue, or engine off gate hold, is an attractive procedural option to conserve fuel at DCA if airlines will accept the procedure. Most of the delay experienced by airlines at DCA occurs when pilots get in line with engines running to wait for their turn to take-off. A departure sequence management system would minimize all of the delays that occur as pilots wait to commence taxi, taxi at slower speeds, and wait in queues for departure clearance.

The baseline estimate for DCA, found fuel use to be 20,103,097 kilograms per year. The use of a paper queue system could produce an annual savings of 7,887,000 kilograms. This estimate is based upon an assumption that the paper queue system would permit an optimum taxi time for departure. Somewhat less fuel would be saved depending upon the amount of delay that would be programmed and actually used to assure that an aircraft is waiting to take-off when a take-off opportunity occurs. The programmed delay represents a planned early arrival in a physical departure queue. The programmed delay will vary from nothing in light traffic to 30 seconds or a minute in heavy traffic situations but should never involve the

sometimes observed lines of 5 to 10 or more aircraft waiting 10 to 15 minutes each.

The problem of determining a minimum prudent planned delay in the paper queue system requires further investigation to determine how the delay varies with traffic:

Table 5.2 presents the distribution of 247 taxi times for DCA departures. Queuing time is not included but the times do include holding intervals. The data confirm the typically short taxi times associated with DCA departures. Only 8 percent of the departures involved taxi times greater than 6 minutes, while 68 percent involved intervals less than 4 minutes. These taxi times are consistent with the calculated taxi times shown in Table 5.2.

Queuing was observed 53 times at DCA. Aircraft were in the queues 10 to 15 minutes in nine instances and one queuing time was 16 minutes and 58 seconds. There are 28 instances when queuing times exceeded 5 minutes. The number of aircraft in the queue was not observed, and each queue represents more than the one aircraft observed as it moved through the queue.

The optimum taxi time for any particular gate location can be defined as the time needed to taxi from pushback location (or gate location if there is no pushback) to the departure point when there is no delay or interference with the taxi activity. The optimum time uses an average or typical taxi speed applicable to non-interference taxi situations but is not the shortest observed time. Faster taxi speeds were observed in some instances.

Each departure problem involves control points where aircraft must stop until ground control gives permission to proceed. Delay associated with control points can occur in two ways. In the first instance, taxi speed is reduced as the control point is approached in anticipation of a clearance to proceed. In the second instance, the aircraft stops at the control point and waits for the clearance. Taxi times greater than the optimum time can be determined in terms of delay probabilities.

TABLE 5.1

DISTRIBUTION OF TAXI TIME AT DCA FOR DEPARTURE

INTERVAL MINUTES (MORE THAN)	NUMBER OF CASES+	FREQUENCY PERCENT	CLASS INVERVAL (MINUTES)	NUMBER OF CASES+
2	247	100	2-3	96
3	151	61	3-4	73
4	78	32	4-5	44
5	34	14	5-6	15
6	19	8	6-7	8
7	11	4	7-8	3
8	8	3	8-9	1
9	7	3	9+	7

+Determined without respect to aircraft type, runway, or airline or gate positions.

TABLE 5.2

Calculated and Observed Outbound Taxi Times – DCA

Gate(s)	Distance from Ramp to Taxiway C (ft)	Time from Ramp to Runway 36		Distance from Ramp to Taxiway J (ft)	Time from Ramp to to Runway 18		Weighted Average Calculated Optimum Time
		Calculated Optimum Time	Observed Optimum Time		Calculated Optimum Time	Observed Optimum Time	
1	1250	2:30		4300	5:15		3:25
2	1100	2:22	2:45	4160	5:08	4:57	3:18
3	1000	2:17		4060	5:03		3:13
4	800	2:07		3660	4:43		2:59
5	630	1:59	2:15	3400	4:30		2:49
6	525	1:54	2:15	3340	4:27	3:55	2:45
7	450	1:50		3300	4:26		2:42
8	400	1:47		3260	4:23		2:39
9-14	350	1:45	2:10	3160	4:18	4:25	2:36
15-17	630	1:59	1:52	2260	4:13	3:00	2:30
18-19	1000	2:17	2:43	2000	3:20	2:12	2:39
20	1200	2:27	2:10	1800	3:10	2:27	2:42
21	1450	2:40		1660	3:03	2:32	2:48
22	1620	2:48	3:49	1500	2:55		2:51
23	1850	3:00		1360	2:48		2:56
24	1900	3:02	2:54	1200	2:40		2:55
25	2020	3:08		1100	2:35	2:57	2:57
26	2150	3:15	3:21	1000	2:30	4:32	3:00
27	2225	3:19		860	2:23		3:00
28	2300	3:22		760	2:18		3:01
29 & 31	2500	3:32	1:56	660	2:13	2:44	3:06
36 & 37	2700	3:42	4:09	380	1:59	2:25	3:08
30 - 38	3000	3:57	4:05	400	2:00	2:05	3:18
40-42	3200	4:07		400	2:00		3:25

The objective of the paper queue is to minimize engine operating time due to on-the-airport delays without adversely affecting airport capacity. Paper queues can eliminate most, but not all, of the delays at control points, but some small amount of delay must be planned to ensure availability of a departing aircraft when departure opportunities occur.

Delays are a function of the number of control points and uncertainties associated with arriving aircraft. Airspace availability for departing aircraft also affects the delay function. Delay estimates can be based upon observations which relate delay at control points to traffic activity. Most delay data does not identify the specific cause for the delay.

Table 5.2 presents calculated optimum taxi times for runways 36 and 18 at DCA. Calculations were made for each gate except for instances when pushback locations for more than one gate were essentially the same. It was assumed that aircraft were pushed back to a clear area on the traffic lane in each instance. Distances were calculated from a layout plan having a scale of 525 feet to the inch.

Two control points affect taxi times for departures on Runway 36. The first control point occurs at the intersection of Taxiway "C" with Runway 3. (See Figure 5.1). The second control point is at the end of Taxiway "C" at Runway 36. Taxi time calculations for R36 departures involve four taxiway segments and speeds as follows:

SEGMENT	DISTANCE	TAXI SPEED
Ramp to Taxiway "C"	Variable	10 ft/sec
Taxiway "C" to R3*	500 Feet	16.89
R3 crossing on "C"*	500 Feet	20.0
R3 to R36 on "C"*	650 Feet	20.0

*Total optimum taxi time for the three taxi segments on Taxiway C is 87.5 seconds.

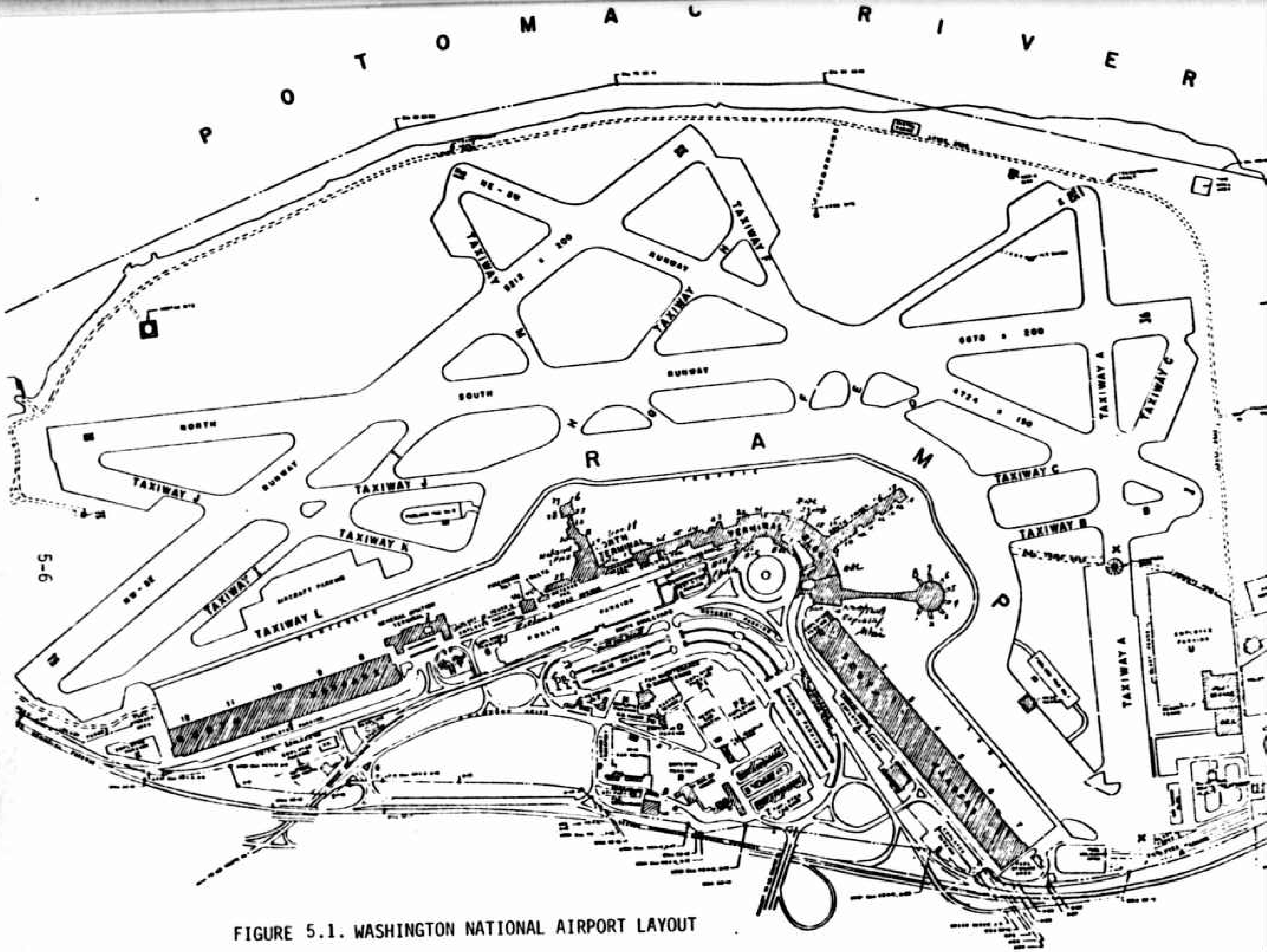

FIGURE 5.1. WASHINGTON NATIONAL AIRPORT LAYOUT

Taxi speeds were selected based upon observed taxi times for a number of departures and are those typically used by various airlines. Taxi speeds along the ramp varied from 15 to 25 feet per second and appear to be limited by pitching and rolling motions induced by the uneven taxiway surfaces. The speeds are slow and were not reduced when aircraft had to pass other B-727 aircraft holding on the runway side of the ramp. General aviation jet aircraft tended to taxi along the ramp at a faster speed, 25 feet per second, except when following an air carrier aircraft.

Slower speeds of about 10 knots, 16.89 ft/sec., were observed for the initial portion of Taxiway C. The need to turn to enter the taxiway and the control point at Runway 3 probably explains the slower speeds. Typical speeds for the remaining segments were 20 feet per second.

Two control points also affect taxi times for departures on Runway 18. One control point involves the Runway 15 crossing for Taxiway "J". The second control point is at the exit from Taxiway "J" onto Runway 18. Taxi time calculations for Runway 18 departures involve four taxiway segments:

SEGMENT	DISTANCE	TAXI SPEED	
Ramp to Taxiway "J"	Variable	20 ft/sec	11.8 knots
Taxiway "J" to R15*	1000 feet	25	14.8
R15 Crossing on "J"*	650 feet	25	14.8
R15 to R18 on "J"*	850 feet	25	14.8

*Total optimum taxi time for the three taxi segments on Taxiway "J" is 100 seconds.

The taxi times shown in Table 5.4 represent no delay situations. Longer times were observed when it was necessary to reduce speed or stop for control points. Optimum taxi times as observed for a number of gates are included in the table for comparison purposes.

The table shows how gate location affects taxi time at DCA. Push-back locations for Gates 5 through 17 permit optimum taxi times of less than 2 minutes for north operations on R36 but require 4 to 5 minutes for south operations on R18. Optimum taxi times for centrally located gates are shown to be 2½ to 3 minutes for either north or south operations. Gates 29 through 42 are shown to be associated with 3½ to 4 minute taxi times for north operations on R36 and 2 minutes for south operations on R18.

North operations occur 66 percent of the time at DCA with approximately 2 departures on R36 for every departure on R18. The final column on Table 5.2 is a weighted average obtained by multiplying R36 taxi time by 2, adding the R18 taxi time and dividing the sum by 3. The weighted optimum taxi times vary from 2½ to 3½ minutes with the longer taxi times associated with Gates 1 and 42.

The savings, by airline and aircraft type, which would accrue from using a paper queue at DCA are listed in Table 5.3. These savings were calculated by multiplying the reduction in taxi time times the fuel flow rate times the number of 1979 departures. The reduction in taxi time was calculated by subtracting from the observed average taxi time for each airline or aircraft type the optimum taxi time shown in Table 5.2. The savings were calculated for the case in which aircraft continue to taxi with one engine shut down only part of the time and for the case in which aircraft always taxi with one engine shut down.

Given current usage of the less than all engine taxi strategy, the airlines would have saved 7,887,741 kg of fuel if a paper queue had been efficiently used at DCA. This would have reduced 1979 fuel consumption on the ground at DCA by 40 percent. Of course, no paper queue scheme would be 100 percent efficient. This analysis did not take into account the amount of time that the aircraft hold with their engines operating before commencing to taxi. It also did not take into account any delay that might take place when the aircraft cross active runways or wait for the departure runway to be clear. No matter how well run the paper queue might be, delays, such as those mentioned above, would not be totally eliminated. However, if only half of the potential savings were realized, almost 4 million kg of fuel, worth about $1.5 million, would be saved.

Fuel conservation opportunities mainly involve delay situations when queuing occurs. Departure sequencing systems using a fixed or average delay to insure availability of an aircraft for take-off would penalize the many situations when delays do not occur.

TABLE 5.3

DCA - POTENTIAL SAVINGS DUE TO USE OF PAPER QUEUE FOR OUTBOUND AIRCRAFT (BASED ON 1979 DATA)

AIRLINE	A/C TYPE	NUMBER OF SECONDS SAVED PER DEPARTURE	ANNUAL SAVINGS (KG FUEL)	
			GIVEN CURRENT USAGE OF TAXIING W/ONE ENGINE SHUTDOWN	GIVEN 100% USAGE OF TAXIING W/ONE ENGINE SHUTDOWN
QH	B737	130	12,145	12,145
	DC-9	130	5,844	3,786
AA	B727	290	1,012,044	697,961
BN	B727	294	439,747	303,274
DL	B727	237	575,029	396,572
	DC-9	237	14,108	9,139
EA	B727	208	794,527	635,622
	DC-9	373	1,598,289	1,035,328
NA	B727	193	353,967	262,198
NW	B727	163	390,246	269,135
PI	B727	353	175,385	120,955
	B737	333	447,265	447,265
RC	DC-9	193	16,945	11,184
TW	B727	284	810,637	559,060
UA	B727	396	680,297	469,170
	B737	138	135,717	135,717
AL	B727	222	36,353	25,071
	DC-9	96	177,979	113,041
	BAC111	101	195,695	161,161
WA	B727	124	15,522	10,725
TOTAL	ALL		7,887,741	5,648,510

The paper queue can be implemented manually or with computer aided sequencing. The more sophisticated system would enable greater savings approaching at least 90 percent of the optimum 7,887,000 kilograms per year. The manual system could be implemented in the short-term without significant cost and might save 50 percent of the optimum amount.

The primary costs of implementing a manual paper queue would be the increased controller workload and the increased communications channel utilitization. The communications problem could probably be easily and inexpensively resolved. The controller workload might be increased by three man years, a small cost compared with the large fuel savings.

Costs of a computer system to manage airport ground traffic sequencing are not known but a cost benefit study is suggested due to the increased benefits expected from such a system. A computer system is an intermediate term option due to the need to expand sequencing program technology.

The paper queue would not affect airport operating safety. It would reduce air pollutant and noise emissions to the extent that it reduced taxi, hold, and queue times. The airport's ability to be expanded or to accommodate future traffic would not be affected. The paper queue is a short-term option (a computer assisted system might be intermediate term) which is both feasible and applicable at DCA. It is also an option which is applicable to most other airports. Further study of this option is suggested.

Engine Start Advisory Procedure

The data collected by the ORI project team indicated that a substantial amount of fuel was consumed by aircraft which held on the ramp after pushback with engines running before commencing to taxi. Some of this hold time may be due to congestion on the ramp. The hold time may also be due, in part, to excessive demands on the ground traffic controller's time. Either of these conditions could limit the controller's ability to grant

permission to taxi. Since pilots cannot easily be aware of such conditions, they may tend to start their engines in anticipation of being promptly cleared to taxi, when, in fact, traffic and communication conditions make such clearance impossible.

To the extent that the above mentioned conditions cause aircraft to hold, with engines running, before commencing to taxi, an engine start advisory procedure would reduce this hold time. The controller would advise pilots about the optimum time to start their engines, so that the pilots would be able to delay their engine start procedure until conditions were such that the pilots could immediately begin taxiing. Under optimum conditions, a pilot might start the engines as early as possible (perhaps during pushback) in order to be able to taxi as soon as the engines were stabilized. At other times, it would be more prudent for the pilots to wait until after pushback to start their engines.

While this procedural option might reduce some of the wasteful pre-taxi engine operating time, it would not be sufficient to solve the problem. An operational effort, discussed below, must also be made. Additional study is needed to determine the cost of implementing an engine start advisory procedure and the degree to which such implementation would reduce pre-taxi hold time.

Independent Procedural Options

Three procedures offer promising fuel conservation opportunities although the amounts of fuel that could be saved are not large or known. Each is used to some extent at the present time and is clearly cost effective. Increased use appears warranted. The three independent procedural options are as follows:

- Minimize start and stop actions
- Maintain unobstructed engine start areas and taxi paths
- Provide a pre-take-off advisory alert to help pilots know when to start the last unstarted engine.

The first option, minimizing start and stop actions, has been widely used by controllers to improve the efficiency of taxi operations and

to maximize airport capacity. This practice also has a favorable effect on fuel consumption. Start and stop actions use more fuel than is consumed by engines operating at idle for the same time period. This is because, once the aircraft stops, the engines must be operated above idle power in order to bring it back into motion. Though the savings accrued from eliminating one single start and stop action may be small, the aggregate savings would be significant. Now that fuel costs have become a major portion of total aircraft operating costs, this option merits even more attention than is currently given it by controllers.

The third option, providing a pre-take-off engine start advisory can be seen as a complement to the procedural option to taxi with one or more engines shut down. This procedure would help the pilot to decide when to start the aircraft's last engine. Many pilots start their last engine when they reach a certain distance from the departure point or when they advance to a certain position in line. If a large number of incoming aircraft must land before the aircraft can enter the runway, the aircraft may have to wait for several minutes, even if it is first in line at the end of the runway.

The controller is better informed about such delays than the pilot. A pre-take-off engine start advisory would effectively transfer this information from the controller to the pilot. A standard system could be implemented in which each departing pilot would receive a signal two minutes before the expected departure time. Using this alert as a guide, the pilot could start the last engine at the most opportune moment, so that the engine would be properly warmed up for take-off but would not operate any longer than necessary. Pilots can currently request information about expected delays, but an automatic advisory would communicate this information much more efficiently and effectively.

The benefits of implementing this option would be to actualize a greater proportion of the potential benefits from taxiing on less than all engines. There would be some costs associated with increasing the workload for ground traffic controllers. If a computerized paper queue system were installed, the pre-take-off alert could probably be incorporated into the system at a low cost. The effects of providing a pre-take-off alert on the

environment, on safety, and on airport expansion and capacity would supplement the effects of taxiing with one or more engines shut down.

OPERATIONAL OPTIONS

Taxiing With One or More Engines Shut Down

Aircraft commonly taxi at DCA with one or more engines shut down in order to save fuel. Current use of this procedure was estimated to have saved 1,312,460 kg of fuel in 1979, worth $236,243 (see Table 5.4). It was further estimated that, had this procedure been used to the fullest extent, 4,603,586 kg, worth $851,663, could have been saved. These dollar savings would be twice as much now as they were in 1979, when fuel prices were only 55¢ per gallon.

Several factors restrict the full implementation of the taxi on less than all engines strategy. Certain aircraft, if heavily loaded, are unable to taxi at idle power unless all engines are operating. Aircraft at DCA generally fly relatively short stage lengths, and are therefore not heavily loaded with fuel. Typically, loaded departing B-727 aircraft at DCA can taxi with two engines operating at idle power. Departing DC-9 and B-737 aircraft, if taxiing with only one engine operating, must generally operate above idle power. Arriving aircraft, which are not heavily loaded with fuel, can generally taxi at idle power with one engine shut down. For all of the above mentioned aircraft, it is more fuel efficient to taxi with one engine shut down, even if it requires a higher power setting, than it is to taxi with all engines operating.

Taxiing with less than all engines requires that the pilot use a higher thrust setting in order to initiate aircraft roll. There may be certain situations in which it is unsafe to use much higher thrust settings, and therefore, the pilot is restricted from taxiing with less than all engines operating.

Finally, on certain two engine aircraft, such as the B-737, where the engines are far from the center of gravity of the aircraft, taxiing with one engine shut down can produce undesirable steering forces. Many operators choose not to employ the strategy for these aircraft. Operators

TABLE 5.4

POTENTIAL AND ACTUAL ANNUAL FUEL SAVINGS
DUE TO TAXIING ON LESS THAN ALL ENGINES
AT DCA
(Based on 1979 Data)

AIRLINE *	AIRCRAFT TYPE	ACTUAL SAVINGS PER YEAR (kg)		POTENTIAL SAVINGS PER YEAR (kg)	
		OUT	IN	OUT	IN
QH	B 737	0	0	13,407	2,439
	DC 9	420	1,290	4,201	1,290
AA	B 727	39,207	117,691	392,062	117,691
BN	B 727	18,567	26,923	185,678	26,923
DL	B 727	25,441	49,195	254,410	49,195
	DC 9	921	1,707	5,007	1,707
EA	B 727	194,812	89,384	389,624	119,179
	DC 9	70,432	157,624	704,328	157,624
NA	B 727	15,895	52,983	158,949	52,983
NW	B 727	19,566	121,854	195,660	121,854
PI	B 727	7,504	34,128	75,040	34,128
	B 737	0	0	286,334	103,959
RW	DC 9	796	1,089	7,961	1,089
TWA	B 727	32,303	98,623	323,034	98,623
UN	B 727	26,941	25,947	269,417	25,947
	B 737	0	0	133,249	70,934
AL	B 727	1,423	5,790	14,230	5,760
	DC 9	9,469	50,349	85,232	50,350
	BAC 111	4,787		47,870	
WA	B 727	758	8,641	7,577	8,641
TOTAL	All	469,242	843,218	3,553,270	1,050,316

*See Appendix J for airline identifiers.

of all types of aircraft generally refrain from using the strategy during precipitation or when taxiing surfaces are slippery, when the maximum amount of steering control is desirable.

Despite these limitations, taxiing on less than all engines is an inexpensive and highly effective fuel conservation strategy, which can be applied, in the short term, to DCA and to most other airports. If used prudently, taxiing with an engine shut down should not have any negative effect on safety. Noise and pollutant emissions would be slightly reduced by the implementation of this strategy. The airport's ability to expand, or to accommodate expected future activity should not be affected.

Starting Engines During Push Back

Starting engines during push back was found to be a widely used technique at DCA. A thorough analysis of aircraft operations at DCA , revealed that the use of this technique actually wasted fuel. By starting engines during push back, pilots were able to reduce their APU use by 15 seconds per operation. This reduction saved about 380,000 kg of fuel in 1979. However, the use of this technique increased engine operation time by about 30 seconds, wasting about 950,000 kg of fuel (see Table 5.5). The costs in terms of aircraft engine fuel consumption far outweigh the benefits of reducing APU use.

It is not clear why aircraft did not commence to taxi immediately after being disconnected from the tow vehicle, if their engines were already operating. Part of the reason may be that the ground traffic controller is often communicating with other aircraft and therefore cannot grant clearance to taxi. Other causes may be the need for pilots to monitor their instruments or communicate with other crew members or with the airline office. Whatever the cause, it is wasteful for pilots to start their engines before they are ready to taxi.

The most efficient push back and taxi method would be as follows: the request for clearance to taxi would be made while the aircraft was at the gate; the ground traffic controller would grant clearance for push back when he/she expected that the aircraft would be able to taxi as soon as the

TABLE 5.5

FUEL SAVED DUE TO A 30 SECOND REDUCTION
IN PRE-TAXI IDLE - DCA
(BASED ON 1979 OPERATIONS)

AIRLINE	AIRCRAFT TYPE	FUEL SAVINGS (KG)*
QH **	B-737	2,803
	DC-9	1,347
AA	B-727	104,554
BN	B-727	44,812
DL	B-727	70,182
	DC-9	1,783
EA	B-727	114,893
	DC-9	128,375
NA	B-727	59,017
NW	B-727	71,728
PI	B-727	14,885
	B-737	40,294
RW	DC-9	2,627
TW	B-727	85,529
UN	B-727	51,468
	B-737	31,809
AL	B-727	4,906
	DC-9	55,618
	BAC-111	58,127
WA	B-727	3,758
TOTAL	All	948,515

* Except for B 737, one engine is assumed to be shut down.
** See Appendix J for airline identifiers.

push back vehicle was disconnected and cleared; the pilot would start the engines at the proper time so that they would be ready for taxiing at the moment the push back vehicle was cleared; the pilot would shut down the APU as soon as the engines were started; the controller would grant clearance to taxi, if possible, as soon as the push back vehicle was cleared; and the pilot would begin taxiing as soon as the towing vehicle was cleared. By using this method, both engine and APU use, and thus fuel use, would be minimized.

The estimated potential fuel cost savings which would have been realized if the method had been used at DCA in 1979 are $68,583. The use of this method would also have a beneficial impact on passenger convenience, on airline revenues, and on noise and air emissions.

This push back and taxi procedure would have to be very efficiently implemented if net fuel savings were to be realized. If 40 percent of the departing aircraft were still required to hold, with engines operating, for 30 seconds, the additional aircraft engine fuel consumption would cancel the APU fuel savings.

Given the current state of communications between pilots and ground traffic controllers, and given current patterns of aircraft ramp congestion, it is likely that at least 40 percent of the aircraft would be delayed. In this case, a better solution would be to institute a more limited program, in which controllers and pilots would try to minimize the amount of time spent holding after push back with engines running but would not seek to minimize APU use. Pilots would refrain from starting engines until they had been pushed back from the gate and were completely ready to taxi. They would thereby reduce engine operation time by 30 seconds, saving the entire 950,000 kg of fuel. APU use would increase by 15 seconds, causing APU fuel consumption to rise by 380,000 kg.

It may be possible to institute a more efficient engine start procedure, but a more thorough evaluation would first be necessary. The ORI team based its findings on observations from the tower of aircraft operations and on interviews with airline and airport personnel. To solve this problem,

pilot operating practice and pilot-controller communication procedures should be monitored and analyzed.

Independent Operational Options

The airlines could realize significant fuel savings if they would more fully implement the following procedures:

- Hold at the gate for departure delays
- Push back to a location which is favorable for taxi route
- Minimize pre-taxi engine operation
- Minimize start and stop actions
- Use the most direct taxi route
- Use the optimum taxi speed
- Minimize last engine operating time
- Arrange for gate exchange to avoid holding for gates.

The implementation of these options requires increased pilot and ground crew effort, increased cooperation and communication between airline personnel and ground traffic controllers, and increased inter-airline cooperation. Many of these options would merely improve the efficiency of other proposed options such as using paper queues or taxiing with one or more engines shut down. The benefits of some of these options can be separately estimated, however.

The benefit of using more direct taxi routes at DCA were evaluated under current operating procedures. The most significant routing problem observed at DCA was the use of the "A" and "J" runway exits by incoming aircraft (See Table 5.6). The fuel loss due to a 10 percent usage of these exits by incoming commercial jet aircraft was estimated to be 250,231 kg. If this practice could be eliminated, an equivalent amount of fuel would be saved.

These options could all be feasibly implemented in the short-term whether separately or in conjunction with other options. None of these options would be costly. These options would generally, reduce engine operating time and thereby noise and pollutant emissions. Most of the options would have negligible effects on safety, but using the optimum taxi speed and minimizing start and stop actions could, if not prudently implemented,

TABLE 5.6

FUEL LOSS DUE TO A 10% USAGE OF TAXIWAYS "A" OR "J" BY COMMERCIAL JET AIRCRAFT AT DCA

AIRCRAFT TYPE	KG USED
B-727	173,758
BAC-111	7,021
DC-9	39,490
B-737	29,962
TOTAL	250,231

have a negative safety impact. These options are generally applicable to other airports.

Aircraft Orientation After Pushback

Aircraft orientation after pushback as well as disconnect location provides opportunities for fuel conservation. Pushback crews typically leave aircraft with an 80^{o} turn towards the taxi direction although some turns were as little as 45^{o}. The crews did not use a more favorable orientation even when no other aircraft were arriving, starting engines, or departing from nearby pushback locations. B 727's needed 18 to 22 seconds to make the 80^{o} turns and B 737's took 10 to 14 seconds to make the turns. One B 737 was observed to make a 270^{o} turn in about 30 seconds. The unusual turn may have been made to avoid jet blast effects on passengers boarding an aircraft at a floating gate near the pushback location. A different pushback location could have been used.

A more favorable orientation after pushback could save the 10 to 20 seconds needed to turn the aircraft towards the direction it will taxi and might also avoid instances when engine starts are delayed to permit other aircraft to taxi past the jet blast area behind the aircraft waiting for permission to start engines. Engine power is increased significantly to make the turns and fuel consumption rates are greater than those associated with engine operation at idle power. The fuel savings for improved orientation is at least equal to the amount of fuel used for 20 seconds with engines operating at idle power. This savings are estimated to be at least 633,333 kilograms per year at DCA.

Aircraft Towing

The short and congested taxiways at DCA are not particularly well suited for towing. Since the fuel savings which would accrue from towing aircraft at DCA are very large, towing was considered to be a potentially promising fuel conservation option. If aircraft were towed from the gates to the end of the departure runway, the aircraft engines would only need to operate for about two and one half minutes (two minutes are required to warm-up the engines, and an average of one half minute would

probably be required to account for unexpected delays). If aircraft were towed from the point at which they exited the arrival runway, the aircraft engines would only need to operate for about one and a half minutes (this time is required to cool the engines). The use of this procedure would reduce engine operating time during a typical arrival-departure cycle from the current average of about ten minutes to about four minutes.

Two scenarios were examined in order to assess the merits of towing aircraft at DCA. Under the first scenario, it was assumed that conventional tow vehicles would be used. Under the second scenario, the use of advanced tow vehicles, capable of towing aircraft at higher speeds, was assumed. The fuel conservation benefits would be the same regardless of the two vehicles used. If aircraft towing had been fully implemented at DCA in 1979, approximately 8.5 million kg of fuel, worth over $3 million at today's prices, would have been saved. The cost of towing aircraft depends very heavily on the type of tow vehicle used.

The following assumptions were made to estimate the cost of towing with conventional tow vehicles:

- Aircraft engines operated for 4 minutes during each arrival/departure cycle. If aircraft had not been towed, they would have taxied with one or more engines shut down.
- Tow vehicles operated at a speed of 7 mph when pulling fully loaded departing aircraft, at 12 mph when pulling arriving aircraft, and at 20 mph when unloaded. Towing increased outbound taxi times by 190 percent and inbound taxi times by 70 percent. Towing added one minute to the hold time for each operation. Return trips made by tow vehicles took 4 minutes.
- Aircraft operating time, and therefore aircraft crew time, was increased by the same factors (see above) as the taxi and hold times.
- Additional APU operating time was equal to the total taxi, hold, and queue time less the 4 minutes of engine operation time.

- Tow vehicle fuel consumption was 0.1 gal/min at $1.30/gallon.
- APU fuel consumption was as listed in Table 5.8 at a cost of $.37/kg.
- Aircraft crew costs were $7.52/min for 3 engine regular body aircraft, and $6.22/min for 2 engine regular body aircraft.[1]
- Total arrival capital and operating costs for 5 medium tow vehicles ($200,000 each), equipment for 5 tow vehicles $85,000 each), maintenance for 10 vehicles ($1,000 each), fuel for 10 vehicles $300,980) and salaries for 10 towing crews ($46,000 each), were about $1.3 million per year.[2] Tow vehicles were assumed to have a 6 year lifespan; 12 percent interest was assumed.

Given these assumptions, the annual cost of towing aircraft with conventional tow vehicles at DCA was estimated to be $9,490,740. This cost exceeds the estimated $3 million fuel cost savings (see Table 5.7).

For the second scenario, the use of advanced tow vehicles was assumed. Since these vehicles operate at faster speeds, each tow operation is shorter and, therefore less costly. The following assumptions were substituted for their counterparts in the first scenario estimates:

- Tow vehicles operated at a speed equivalent to normal aircraft taxi speeds. Tow vehicle operation time per arrival/departure cycle was 12 minutes.
- Aircraft crew time was increased by 2 minutes per cycle.
- Additional APU operation time was equal to the total taxi, hold, and queue time less 4 minutes.

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[1] These estimates, like much of the methodology employed, were developed by Peat, Marwick, Mitchell & Company for their Aircraft Towing Feasibility Study, published in September 1980 for the U.S. Department of Energy.

[2] Much of this data is also from the PMM study.

TABLE 5.7

ESTIMATED BENEFITS AND COSTS OF TOWING AIRCRAFT AT DCA

(BASED ON 1979 OPERATIONS DATA, 1981 PRICES)

	CONVENTIONAL TOW VEHICLES	ADVANCED TOW VEHICLES
AVIATION FUEL SAVED	8,488,090 kg ($3,140,593)	8,488,090 kg ($3,140,593)
Additional Aircraft Crew Cost	($7,722,257)	($1,343,680)
Additional APU Fuel Consumption	2,044,603 kg ($756,503)	553,601 kg ($204,832)
Additional Tow Vehicle Fuel Consumption	231,524 kg ($300,980)	-
Annualized Cost of 5 Medium Tow Vehicles	($240,000)	-
Annualized Cost of Other Equipment	($ 6,000)	-
Annual Maintenance Costs	($ 5,000)	-
Annual Cost of 10 Tow Crews	($460,000)	-
Cost per Tow Vehicle Operation	-	$4/minute
Total Annual Cost of Tow Vehicle Operation	($1,011,980)	($4,619,664)
Total Annual Cost of Towing	($9,490,740)	($ 6,168,176)

- Tow vehicle operation and capital cost was $4 per minute of operation.[3]

Given these assumptions, towing aircraft with advanced tow vehicles at DCA would cost over $6 million per year. Of this total cost, about $1.3 million would be attributable to additional aircraft crew times, $200,000 to additional APU fuel consumption and $4.6 million to tow vehicle capital and operating costs. This tow vehicle cost estimate could easily be 50 to 100 percent higher. Even given the lower estimate, however, the total costs of towing exceed the value of the fuel saved ($3 million).

The noneconomic impacts of towing aircraft at DCA are mixed. Prolonged and frequent towing could have an adverse impact on safety, if it damaged the aircraft nose gear. Evidence of such a problem is to date inconclusive. Towing would have a positive impact on the environment, since both noise and air pollution emissions would be reduced.

Towing would probably severely complicate operations at DCA, limiting its ability to handle current traffic activity. The airport's ability to handle future traffic would be similarly affected. Future airport expansion would not be affected.

Although towing is an option which could be implemented at DCA, the complications that it would create and its unfavorable economics probably prevent it from being a prudent option at DCA. Towing may be more promising at larger and less busy airports.

AIRPORT LAYOUT CHANGES

Taxiway Improvement

Rough and uneven taxiways at Washington National Airport are responsible for the slow taxi speeds used by most pilots to reduce passenger

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[3] This estimate was made by Vanley Systems, a tow vehicle manufacturer, and published in the PMM study. This figure implies that the advanced tow vehicles will be slightly less costly to operate than conventional tow vehicles, even though their fuel consumption is much higher.

discomfort. Taxi speeds could be increased to 35 or 40 feet per second if surfaces were not so rough. However, reducing taxi times to less than 2 minutes is close to the minimum engine operating time needed to prepare for take-off. Inspection of Table 5.2 indicates that optimum taxi times vary from 2 to 5 minutes, approximately. Better taxiway surfaces would reduce the longer times to about 2½ minutes. An average optimum taxi time using the faster taxi speeds would be approximately 2¼ minutes.

The fuel savings associated with improved taxiway surfaces can be estimated by calculating optimum taxi times for each gate using the faster 40 foot per second taxi speed except for the final 650 foot section of Taxiway "C" and the final 850 foot section of Taxiway "J". Taxi speeds might not be increased on these final taxiway segments if surface roughness is reduced. The savings due to improved surfaces would be the difference in calculated optimum taxi times multiplied by the fuel used for all engine operation times the number of operations.

A 30 second reduction in average optimum taxi times would save 950,000 kilograms of fuel per year at DCA. These savings are in addition to savings attributed to the paper queue.

Additional taxiways to reduce fuel consumption at DCA are not feasible. However, a high speed turn off at Taxiway "I" to permit aircraft to turn onto Taxiway "K" would reduce Runway 36 occupancy time and the number of times aircraft are unable to use an optimum runway exit. The turnoff would also reduce the number of R33 crossing delays. The savings result from three factors:

- Direct route conservation
- Reduced delay on the ground for R36 and R33 departures
- Reduced delay in the air for R36 or R33 arrivals.

The direct route savings were estimated to be 250,231 kilograms per year. Savings due to arrival and departure delay reduction would be significant but would require additional study to quantify.

Special Holding Areas

Taxiways "A" and "L" are presently used as special holding areas when gate release and air delays affect aircraft departures to a congested destination. Use of either special holding area increases taxi distance and engine and APU operating times. Enlarging the final sections of Taxiways "C" and "J" would accomplish the same purpose without increasing taxi distance.

The savings associated with special holding areas cannot be estimated with reasonable accuracy on the basis of available information because the number of occasions when such areas are needed is not known. Also, operational procedures to use vacant gates normally used by another airline would solve many gate release problems with no additional capital costs. Construction of improved special holding areas is not a prudent choice if other options can be implemented.

Runway Extensions

A 1,000 foot extension to Runway 3-21 appears to be feasible at the south end of the runway. Depending upon aircraft weight and power, many B-727, DC-9, and B-737 flights could use a 5,724 foot Runway 3 for departure. Such an extension would reduce delay in the air as well as on the ground. A similar extension on the south end of Runway 36 would increase the probability that a direct route exit could be made for arrivals. However, the R36 expansion would complicate runway instrumentation for approach and feasibility is not assured without a more detailed investigation.

The potential benefit of either runway extension on fuel conservation warrants further study.

Additional Runways

Construction of additional runways was considered as a fuel conservation option for DCA but did not appear to be practical.

Additional Gates

Additional gates would be possible if the north hanger area for maintenance could be relocated. One or more additional fingers on either

side of the north terminal would also increase gate positions. However, the additional fingers would cause further congestion along the apron and would adversely affect taxi activity and speed. Remote gates and mobile lounges were also considered but do not appear to be practical because of the lack of aircraft parking space.

Additional gates do not appear to represent a practical fuel conservation option.

Assessment of Taxiway and Runway Improvement Options

DCA Construction Plan and Costs. FAA has selected a consulting firm and is preparing to contract for a Master Planning Study. Existing budget plans mainly cover airport rehabilitation and maintenance. No new runways or runway extensions are comtemplated but an overrun at the north end of 36 is planned.

A new runway and associated taxiway are estimated to cost between 2 and 3 million dollars for each 1,000 feet. A recently constructed runway cost $2 million per 1,000 foot length. A higher cost would be expected for an extension to an operational runway.

Reconstruction projects are planned and proposed that are of consequence to fuel conservation at Washington National. These include the following:

- Ramp Apron and connecting taxiways
  - 1983 - $3.5 million
  - 1984 - $3.0 million
  - 1986 - $3.5 million
  - 1987 - $4.0 million
- South Apron between the satellite terminal extensions
  - 1985 - $2.3 million
- North Terminal Apron
  - 1985 - $1.6 million
- Widen holding area on Taxiway C near the south end of Runway 18-36

- 1984 - $2.75 million

- Taxiway I. Construct a fillet to reduce the sharp turn necessary to exit Taxiway I onto Taxiway J.

- Reconstruct Taxiway A between Runways 18-36 and 3-21.

The Use of Fixed Ground Power Systems

Although the focus of this study has been on fuel consumed by aircraft engines during taxi, hold, and queue operations, it is also useful to examine the manner in which fuel is consumed by aircraft while they are parked at the gate. Parked aircraft require electrical power for the operation of certain instruments and lights, and they require pneumatic power for the operation of heating and cooling systems (during hot or cold weather) and for starting the main engines. This electrical and pneumatic power can be supplied by aircraft mounted gas turbine auxiliary power units (APUs), by diesel powered ground power units (GPUs), or by electrically powered fixed ground power systems (FPS's). The capital and operating costs of these three power sources vary widely.

Since APU's are standard equipment on most modern commercial aircraft, the capital cost is effectively zero. The fuel consumed by APU's is, however, very high in comparison with the alternative power sources (see Table 5.8). Airlines typically use two different types of diesel powered GPU's; one type for electrical power and one type for both electrical and pneumatic power.

The airlines at DCA generally provide GPU's for producing electrical power, but they are not well equipped with GPU's for producing both electrical and pneumatic power. In the short term, the capital cost of employing GPU's for the production of electrical power is negligible, but the capital cost for producing electrical and pneumatic power from GPU's (at $120,000 per unit) is very high. GPU's do, however, consume considerably less fuel than APU's.

A few of the airlines at DCA[1] currently used fixed ground electrical systems. The capital cost of installing these systems is substantial. However, if over eight gates were served by a single system, the cost of an electri-

[1]TWA and NW.

TABLE 5.8

HOURLY OPERATING AND MAINTENANCE COSTS*

AIRCRAFT TYPE	ELECTRICAL ONLY			ELECTRICAL & PNEUMATIC		
	APU	GPU	FPS	APU	GPU	FPS
Narrow Body	$ 32	$ 4.30	$ .75	$45	$16	$10
Wide Body (2-3 Engine)	70	6.50	1.20	75	31	18
B-747	141	17.00	1.70			

*Fuel cost assumed to be $1.00 per gallon.

SOURCE: Dexter R. Groose, "Fuel Conservation Techniques for Aircraft on the Ground," paper presented before the ATA Engineering and Maintenance Forum, October 1-3, 1980.

cal fixed power system at DCA would be about $40,000 per gate. The cost of a similar system which would provide both electrical and pneumatic power would be about $150,000. The fuel and operating savings would be substantial however (see Table 5.9).

The annual operating and maintenance cost savings which would accrue from using FPS's or GPU's at DCA can be compared in Table 5.9 against the annualized capital costs for these systems. The cost figures were obtained by multiplying the number of 1979 arrivals by airline and aircraft type times the cost figures in Table 5.8. Thirty minutes of electrical and pneumatic power utilization per arrival/departure cycle, a very conservative estimate, was assumed in these calculations. The capital costs were obtained by interviewing airline engineers and managers and fixed power system industry sources. The cost per gate was multiplied by the number of gates for each airline. A 12 percent interest rate was assumed, as was a lifespan of 20 years for fixed power systems and 10 years for diesel ground power units.

Analysis of these operating and capital costs reveals that fixed power systems are generally cost effective for the airlines at DCA (see Table 5.10). In the short term, if the capital cost for GPU's which produce electrical power only is assumed to be zero, fixed power systems are generally less cost effective than GPU's. Over the long term, however, as new GPU's are purchased, fixed power systems become more cost effective. For the provision of both electrical and pneumatic power, fixed power systems are almost universally more cost effective than either APU's or GPU's.

In light of the economic advantages of fixed power systems, it is interesting that only two airlines have installed them at DCA. One problem is that no single airline uses more than seven of the airport's gates. The smaller the number of gates in the system, the greater the per gate capital cost of the system. The preceding analysis was based upon the assumption that at least eight gates would be incorporated into a single system. For true economics of scale to be realized, more than one airline would have to be included in the system. Joint ventures in fixed power systems are becoming more common throughout the country, and at least two other airlines (Eastern and U.S. Air, with a combined total of 9 gates plus two parking positions) are

TABLE 5.9

ESTIMATED BENEFITS AND COSTS OF INSTALLING FIXED POWER SYSTEMS AT DCA

(BASED ON 1979 OPERATIONS DATA, 1981 COSTS)

	ANNUAL OPERATION COST SAVINGS					ANNUALIZED CAPITAL COST		
	ELECTRICAL ONLY		ELECTRICAL & PNEUMATIC			ELECTRICAL ONLY	ELECTRICAL AND PNEUMATIC	
	FPS OVER APU	FPS OVER GPU	FPS OVER APU	GPU OVER APU	FPS OVER GPU	FPS[1]	GPU[2]	FPS[3]
QH *	8,529	967	9,828	8,190	1,638	5,355	21,238	20,082
AA	146,468	16,597	168,786	140,655	28,131	31,131	127,428	120,492
BN	62,777	7,114	72,342	60,285	12,057	5,355	21,238	20,082
DL	93,892	10,640	108,198	90,165	18,033	16,065	63,714	60,246
EA	456,947	51,779	526,572	438,810	87,762	32,131	127,428	120,492
NW	100,483	11,386	115,794	96,465	19,299	21,421	84,952	80,328
PA	82,677	9,369	95,274	79,395	15,879	16,065	63,714	60,246
PI	102,598	11,625	118,206	98,502	19,704	21,421	84,952	80,328
TW	106,044	12,016	122,202	101,835	20,367	21,421	84,952	80,328
UA	136,601	15,482	157,446	131,205	26,241	26,776	106,190	100,410
AL	200,826	22,757	231,426	192,855	38,571	16,025	63,714	60,246
RC	5,358	607	6,174	5,145	1,029	5,355	21,238	20,082
TOTAL	1,503,200	170,339	1,732,248	1,443,507	288,711	219,561	870,758	823,362

NOTES: [1]$40,000 pergate, 20 yr lifespan, 12 percent interest.
[2]$120,000 per unit, 1 unit per gate, 10 yr lifespan, 12 percent interest.
[3]$150,000 per gate, 20 yr lifespan, 12 percent interest.
*See Appendix J for airline identifiers.

considering such an arrangement at DCA. Extreme economics of scale could be realized if the entire airport were equipped with a single central fixed power system. Many airlines are wary of this kind of venture, since they are reluctant to become dependent upon a system over which they would have little control.

Another problem at DCA is that aircraft engines cannot be started while the aircraft is at the gate. Therefore, a fixed pneumatic power system cannot provide the power needed to start the aircraft engines. A mobile system, such as an APU, a GPU, or bottled start air must be used instead. It is probably most efficient at DCA to use GPU's for this purpose.

The most serious barrier to the installation of fixed power systems at DCA is the size of the necessary capital investment. The combined effect of airline deregulation, fuel price increases, and the economic downturn has been a reduction in the profitability of many of the airlines which operate at DCA. While the airlines' profits have declined, their capital requirements have grown. Many of the airlines are undertaking massive programs to purchase new aircraft. Fixed power systems must compete against other very important capital goods in the battle for the airlines' investment outlays. The example set by U.S. Air at Pittsburgh, where their new electrical and pneumatic fixed power system is expected to pay for itself in two years, may increase the incentive for airlines to allocate some of their scarce capital to the purchase of FPS's.

In addition to the positive fuel conservation and economic impacts of installing FPS's, the non-economic effects would also be generally favorable. These systems reduce the dependence of the airlines on oil, enhancing their energy security. The noise emitted from FPS air compressors is controllable and would be completely offset by reductions in APU and GPU noise and pollutant emissions. The use of FPS's would reduce airport ramp clutter, potentially increasing airport efficiency and capacity. Safety would be unaffected, as would the airport ability to expand and to accommodate expected future activity. Installing fixed power systems is a short term option which is both applicable and feasible at DCA, just as it is at almost any other busy commercial airport.

Alternate methods of providing aircraft heating and air conditioning deserve and are receiving further study. The Air Transport Association is currently studying methods of providing aircraft with preconditioned air from specially equipped trucks or from the terminal, in order to compare the utility of these systems with that of fixed pneumatic power systems.

VI. DULLES INTERNATIONAL AIRPORT

This section presents the procedural and operational practices and options applicable to Dulles International Airport (IAD).

PROCEDURAL OPTIONS

Paper Queue

Lengthy delays for departing commercial aircraft are rare at IAD. On-site investigations at IAD revealed that only 12.5 percent of the total fuel burned during ground operations at IAD was burned while aircraft were holding or queuing. If all of this hold and queue time had been eliminated, approximately 400,000 kg of fuel would have been saved during 1979. Though the time spent holding or queuing at IAD is relatively short, the amount of fuel burned during this time is very significant because the aircraft are generally large.

Some of this fuel burn could be eliminated if an informal paper queue system was implemented at IAD. Taking into consideration the distance from an aircraft's parking position to each of the departure runways, the number of aircraft waiting to take-off on each of those runways, and the number of aircraft approaching to land on each of those runways, the controller could advise the aircraft's pilot to taxi to a specific runway or to hold briefly at the gate in order to minimize the aircraft's taxi and hold time. If the controller advised holding at the gate, the aircraft's position in line would have to be maintained. At Dulles, the competitive urge to gain a position in queue is not so strong as at DCA, since large numbers of competing air carrier aircraft rarely depart from IAD at the same

time. The airlines would, therefore, be more amenable to the implementation of a paper queue at IAD than at DCA. The procedural impediments to using a paper queue at IAD would be small, since the system would be rarely used, the hold time for each aircraft would be brief, and the number of aircraft in each queue would be small.

Implementing an informal, manual paper queue is a feasible short term option at IAD. In the long-term, if activity increases at Dulles, a more formal and sophisticated system (perhaps a computer assisted ground management system) might be warranted. This short-term option would be applicable to and feasible for any airport which has low traffic activity but large aircraft. The system would be practically without cost to institute and operate. The principal requirement is simply an increased effort by pilots and ground traffic controllers to reduce aircraft taxi and hold time. Effects on pollutant and noise emissions would be minor but positive. The procedure would not affect airport safety. Future airport expansion or traffic accommodating capability would be unaffected.

<u>Engine Start Advisory Procedure</u>

Since aircraft are not pushed back from the gate and aircraft traffic on the apron is usually very light, an engine start advisory procedure is unnecessary at IAD. Pilots are generally able to start their engines, request and receive clearance to taxi, and begin taxiing without delay. An engine start advisory would only be needed at IAD if, during a departure delay situation, the ground traffic controller was using a paper queue and had advised the pilot to hold at the gate. In that case, the engine start advisory would be an integral part of the paper queue procedure.

<u>Independent Procedural Options</u>

The three independent procedures considered for DCA would also be applicable to operations at IAD. These options are:

- Minimizing start and stop actions during taxi.
- Maintaining unobstructed engine start areas and taxi paths.

- Providing pre-take-off advisory to help pilots know when to start the last engine(s).

As at DCA, these options are feasible for short-term implementation at IAD. The cost of implementation would be low, but the benefits would be significant.

OPERATIONAL OPTIONS

Taxiing With One or More Engines Shut Down

Taxiing with one or more engines shut down is a commonly used fuel saving procedure at IAD. Study of aircraft operations at IAD revealed that the use of this strategy in 1979 saved an estimated 838,706 kg of fuel, worth $155,161. Had the procedure been utilized to the fullest extent, 1,733,618 kg of fuel worth $320,719, would have been saved. The actual and potential savings would be, respectively, $310,322 and $641,139 at today's fuel prices. The savings, by airline and aircraft type, are listed in Table 6.1.

The analysis of the use of this strategy at DCA applies generally to IAD. Aircraft are typically more heavily loaded at IAD than at DCA, because they generally fly longer stage lengths. The result is that pilots of departing aircraft must generally set their engines above idle power when taxiing with one or more engines shut down. It is still more fuel efficient for most of the aircraft operating at IAD to taxi with one or more engines shut down than with all engines operating. The higher thrust settings needed to initiate aircraft roll do not pose as many safety problems at IAD as they do at the more crowded DCA. Taxiing on less than all engines is a short-term strategy which is both feasible and applicable at IAD.

Independent Operational Options

Airlines operating at IAD could benefit from the implementation of several of the independent procedures proposed for DCA, including:

- Hold at the gate for departure delays
- Minimize pre-taxi engine operation
- Minimize start and stop actions
- Use the most direct taxi route

TABLE 6.1

POTENTIAL AND ACTUAL ANNUAL FUEL SAVINGS
DUE TO TAXIING ON LESS THAN ALL ENGINES AT IAD
(BASED ON 1979 DATA)

AIRLINE*	AIRCRAFT TYPE	ACTUAL SAVINGS (kg)		POTENTIAL SAVINGS (kg)	
		OUT	IN	OUT	IN
AA	B 727	1,974	15,413	19,749	15,413
	B 707	0	46,455	120,847	46,455
	B 747	0	106	87	106
	DC 10-10	0	39,124	10,291	39,124
BN	B 727	8,504	42,211	85,037	42,211
	DC 8	0	13,106	8,895	13,106
	SSC	0	56,690	46,810	56,690
CO	B 727	3,431	22,269	34,314	22,269
DL	B 727	741	5,780	7,406	5,780
	DC 8	0	220	176	220
	DC 9	777	5,630	7,767	5,630
	L 1011	0	34	35	34
EA	B 727	5,189	38,146	51,887	38,146
	DC 9	1,096	7,942	10,959	7.942
	L 1011	0	34	35	34
NW	B 727	47	343	466	343
	B 747	0	37,054	30,558	37,054
	DC 10-40	0	22,277	29,568	22,227
OZ	DC 9	1,681	11,333	14,007	11,333
PA	B 707	0	12,580	32,725	12,580
	B 747	0	116,041	58,227	116,041
PI	B 727	9	64	87	64
	B 737	0	0	616	578
RC	DC 9	2,957	12,299	20,534	23,762
TW	B 727	379	2,782	3,786	2,782

TABLE 6.1 (Continued)

AIRLINE*	AIRCRAFT TYPE	ACTUAL SAVINGS (kg)		POTENTIAL SAVINGS (kg)	
		OUT	IN	OUT	IN
TW (Continued)	B 707	0	47,281	122,994	47,281
	B 747	0	424	348	424
	DC 9	6	43	59	43
	L 1011	0	22,788	23,759	22,788
UA	B 727	963	4,233	9,626	4,233
	B 737	0	0	8,441	3,509
	B 747	0	212	174	212
	DC 8	0	90,717	72,182	90,717
	DC 10	0	10,390	23,600	10,390
BA	B 747	0	26,033	21,853	26,033
	SSC	0	38,284	31,612	38,284
AF	SSC	0	51,045	42,149	51,045
TOTAL		27,754	810,846	957,666	775,759

*See Appendix J for airline identifiers.

- Use the optimum taxi speed
- Minimize last engine operating time.

These options are, to varying degrees, in current use by pilots at IAD. Many pilots could increase their efforts to implement these options, however. Some of these options would merely improve the efficiency of other proposed options.

Using the most direct taxi route is a very important option which merits further discussion. The airport layout for Dulles International Airport is shown in Figure 6.1. Distances from runways to gates are large compared to distances at Washington National Airport. Therefore, the need to exercise direct route taxi options to conserve fuel is greater at Dulles than at Washington National. Fortunately, the freedom to exercise direct route options is also greater because of the lack of heavy traffic. Aircraft were observed to land on either runway and to use the shortest taxi route during the data collection period.

The commercial air carriers tended to use the 19R-01L runway in order to avoid the general aviation traffic on the 19L-01R runway. For departing commercial aircraft, the left runways were generally preferred over the right runways because the end of the runway is closer to the apron for left rather than for right runways. During South operations, the 19R runway was sometimes used by departing air carriers because of heavy traffic on 19L. No departures were observed on the 01R runway.

Inbound commercial aircraft generally exited near the middle of the runway, so there was no substantial difference between taxi distances for right runway operations and taxi distances for left runway operations. Left runway arrivals must make a sharper turn than right runway arrivals, but this factor seemed to have no effect on runway use preferences at IAD. The major factor affecting runway preference for inbound aircraft was the heavy GA traffic on the 19L-01R runway.

In most every case, the air carriers chose to use the runway which made possible the use of the most efficient taxi route between the runway and the apron. It was not clear, however, that the inbound air carriers

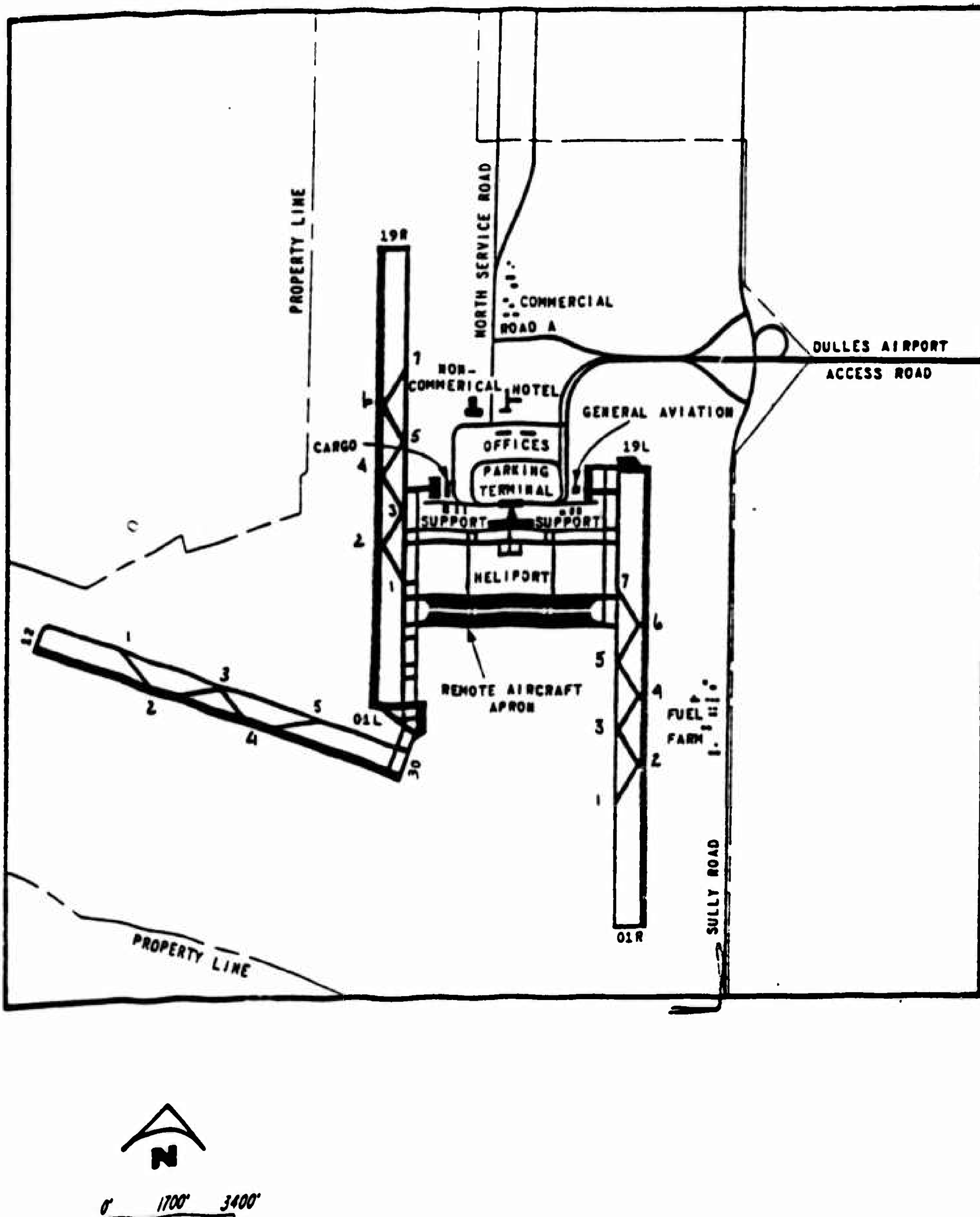

FIGURE 6.1. DULLES INTERNATIONAL AIRPORT LAYOUT

always adequately considered their ultimate destination on the apron. Outbound air carriers appeared to consider this factor more closely. Substantial fuel savings would result from reducing taxiing on the apron at IAD. These savings could be achieved through more careful consideration of apron position when choosing which runway to use. Additional savings would result from allowing air carriers to taxi in a counterclockwise direction on the apron in cases in which the use of the procedure would shorten taxi distances. Controllers at Dulles often allow this practice upon request of the pilot, but the practice is not utilized as often as it could be. The low volume of traffic at Dulles and the large size of the taxiways would allow the use of two-way traffic on the apron almost all of the time without compromising safety. The amount of fuel which could be saved through more careful runway choice and the enhanced use of two-way traffic at IAD can scarcely be quantified, but given the large taxi distances required at IAD and the size of the aircraft, a small percentage reduction in taxi times at Dulles would save very large quantities of fuel. The scale of these potential savings is presented in Table 6.2, which shows how much fuel is consumed during one minute of inbound taxiing by each of the major aircraft types at IAD.

The scale of the potential benefits of holding at the gate for departure delays, minimizing pre-taxi engine operation, and using the optimum taxi speed (generally faster than current speeds) can also be seen on Table 6.2, since all of these options reduce the time during which engines operate at idle. Minimizing start and stop actions reduces not only the total taxi time but also the number of times that engine power must be increased to initiate aircraft roll. Minimizing last engine operation time is merely a corrollary to taxiing with one or more engines shut down and providing pre-take-off engine start advisories.

These options could all be feasibly implemented in the short-term either separately or in conjunction with other options. None of these options would be costly. These options would, generally, reduce engine operating time and thereby noise and pollutant emissions. Most of the options would have negligible affects on safety, but using the optimum taxi speed

TABLE 6.2

FUEL CONSUMED BY LARGE AIRCRAFT AT
IAD DURING ONE MINUTE OF INBOUND TAXIING

AIRCRAFT TYPE	ENGINE TYPE	FUEL CONSUMED DURING ONE MINUTE OF INBOUND TAXIING (kg)	
		All Engines	Less than all Engines
SSC	Olympus 593	101	51
B 747	JT9D	51	25
DC 10	CF6	23	19
	JT9D	38	25
L 1011	RB211	31	21
B 707	JT3D	27	14
DC 8	JT3D	27	16
B 727	JT8D	23	15
DC 9	JT8D	15	8
B 737	JT8D	15	--

and minimizing start and stop actions could, if not prudently implemented, have a negative safety impact. These options are generally applicable to other airports.

Aircraft Towing

Because the taxiways at Dulles are very long, and because the aircraft are generally large, towing was considered to be a potentially promising fuel conservation procedure. If aircraft were towed from the apron parking positions to the end of the departure runway, the aircraft engines would only need to operate for about two and one half minutes (two minutes are required to warm-up the engines, and an average of one half minute would probably be required to account for unexpected delays). If aircraft were towed from the point at which they exited the arrival runway, the aircraft engines would only need to operate for about one and a half minutes (this time is required to cool the engines). The use of this procedure would reduce engine operating time during a typical arrival-departure cycle from the current average of about ten minutes to about four minutes.

Two scenarios were examined in order to assess the merits of towing aircraft at IAD. Under the first scenario, it was assumed that conventional tow vehicles would be used. Under the second scenario, the use of advanced tow vehicles, capable of towing aircraft at higher speeds, was assumed. The fuel conservation benefits would be the same regardless of the tow vehicle used. If aircraft towing had been fully implemented at IAD in 1979, approximately 1.8 million kg of fuel, worth almost $700,000 at today's prices, would have been saved. The cost of towing aircraft depends very heavily on the type of tow vehicle used, however.

The following assumptions were made to estimate the cost of towing with conventional tow vehicles:

- B-707 and DC-8 aircraft were not towed because they are not equipped with APU's.
- Aircraft engines operated for 4 minutes during each arrival/departure cycle. If aircraft had not been towed, they would have taxied with one or more engines shut down.

- Tow vehicles operated at a speed of 7 mph when pulling fully loaded departing aircraft, at 12 mph when pulling arriving aircraft, and at 20 mph when unloaded. Towing increased outbound taxi times by 190 percent and inbound taxi times by 70 percent. Towing added one minute to the hold time for each operation. Return trips made by tow vehicles took 4 minutes.

- Aircraft operating time, and therefore aircraft crew time, was increased by the same factors (see above) as the taxi and hold times.

- Additional APU operating time was equal to the total taxi, hold, and queue time less the 4 minutes of engine operation time.

- Tow vehicle fuel consumption was 0.1 gal/min at $1.30/gallon.

- APU fuel consumption was as listed in Table 5.8 at a cost of $.37/kg.

- Aircraft crew costs were $11.25/min for 4 engine widebody aircraft, $9.40/min for other 4 engine aircraft, $8.93/min for 3 engine widebody aircraft, $7.52/min for other 3 engine aircraft, and $6.22/min for 2 engine aircraft.[1]

- Total annual capital and operating costs for 5 large tow vehicles ($300,000 each), 5 medium tow vehicles ($200,000 each), equipment for 10 tow vehicles ($3,000 each), maintenance for 10 vehicles ($1,000 each), fuel for 10 vehicles ($53,431), and salaries for 15 towing crews ($46,000 each), were about $2 million per year[2]. Tow vehicles were assumed to have a 6 year lifespan; 12 percent interest was assumed.

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[1] These estimates, like much of the methodology employed, were developed by Peat, Marwick, Mitchell & Company for their Aircraft Towing Feasibility Study, published in September 1980 for the U.S. Department of Energy.

[2] Much of this data is also from the PMM study.

Given these assumptions, the annual cost of towing aircraft with conventional tow vehicles at IAD was estimated to be $3,168,095. This cost far exceeds the estimated $700,000 fuel cost savings (see Table 6.3).

For the second scenario, the use of advanced tow vehicles was assumed. Since these vehicles operate at faster speeds, each tow operation is shorter and, therefore less costly. The following assumptions were substituted for their counterparts in the first scenario estimates:

- Tow vehicles operated at a speed equivalent to normal aircraft taxi speeds. Tow vehicle operation time per arrival/departure cycle was 12 minutes.
- Aircraft crew time was increased by 2 minutes per cycle.
- Additional APU operation time was equal to the total taxi, hold, and queue time less 2 minutes.
- Tow vehicle operation and capital cost was $4 per minute of operation.[3]

Given these assumptions, towing aircraft with advanced tow vehicles at IAD would cost over $1 million per year. Of this total cost, $250,000 would be attributable to additional aircraft crew times, $50,000 to additional APU fuel consumption and $800,000 to tow vehicle capital and operating costs. This tow vehicle cost estimate could easily be 50 to 100 percent higher. Even given the lower estimate, however, the total costs of towing exceed the value of the fuel saved ($700,000).

The noneconomic impacts of towing aircraft at IAD are mixed. Prolonged and frequent towing could have an adverse impact on safety, if it damaged the aircraft nose gear. Evidence of such a problem is to date inconclusive. Towing would have a positive impact on the environment, since both noise and air pollution emissions would be reduced. Towing would not

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[3] This estimate was made by Vanley Systems, a tow vehicle manufacturer, and published in the PMM study. This figure implies that the advanced tow vehicles will be slightly less costly to operate than conventional tow vehicles, even though their fuel consumption is much higher.

TABLE 6.3

ESTIMATED BENEFITS AND COSTS OF TOWING AIRCRAFT AT IAD

(BASED ON 1979 OPERATIONS DATA, 1981 PRICES)

	CONVENTIONAL TOW VEHICLES	ADVANCED TOW VEHICLES
AVIATION FUEL SAVED	1,780,917 kg ($658,939)	1,780,917 kg ($658,939)
Additional Aircraft Crew Cost	($1,695,163)	($256,615)
Additional APU Fuel Consumption	290,543 kg ($107,501)	120,129 kg ($ 44,448)
Additional Tow Vehicle Fuel Consumption	144,408 kg ($53,431)	-
Annualized Cost of 5 Large Tow Vehicles	($360,000)	-
Annualized Cost of 5 Medium Tow Vehicles	($240,000)	-
Annualized Cost of Other Equipment	($ 12,000)	-
Annual Maintenance Costs	($ 10,000)	-
Annual Cost of 15 Tow Crews	($690,000)	-
Cost per Tow Vehicle Operation	-	$4/minute
Total Annual Cost of Tow Vehicle Operation	($1,365,431)	($788,016)
Total Annual Cost of Towing	($3,168,095)	($1,089,079)

limit expansion at IAD (if it were envisioned), nor would it restrict the ability of the airport to accommodate expected future traffic activity. It would, however, make current operations at IAD somewhat less efficient.

Towing aircraft with conventional tow vehicles is probably a technically feasible short-term option for IAD. Towing with advanced tow vehicles is an intermediate term option. Towing could be applied to almost any airport, excepting those where crowded taxiways or extreme capacity utilization might make it impractical. However, since towing is uneconomic at IAD, which seems ideally suited for it, towing is not a fuel conservation option which is likely to be implemented at other airports. As advanced tow vehicles are introduced, the economics could change. This is an option that merits additional study.

AIRPORT LAYOUT CHANGES

Taxiway Improvement

Because of the vast size of IAD, taxi distances are very long. The airport is well designed, however, so there are few possibilities for shortening the taxi distances. Only one problem was noted which could be alleviated by making a relatively minor airport layout change.

GA aircraft generally use the 19L-01R runway, since it is closer to the GA terminal. The runway length necessary to land and brake many GA aircraft is far shorter than the distance between the end of 19L and Exit 6.* Ground taxi times could be substantially reduced for many GA aircraft if there were an exit halfway between the end of 19L and Exit 6. This exit could be a simple extension of the South entrance to the General Aviation terminal. Shortening the time that GA aircraft spend taxiing on the runway would save fuel indirectly by reducing the time that departing aircraft must wait to use 19L and by making 19L more available to incoming aircraft.

An estimate was made of the potential fuel savings which would be realized if such a taxiway were constructed. It was assumed that 20 percent of all departing commercial jet aircraft use 19L and that 10 percent of these aircraft must wait one minute, with all engines operating, for small GA aircraft to exit the runway. If these delays had been eliminated

*This exit number is based upon the numbering system used in Figure 6.1.

in 1979, an estimated 12,000 kg of fuel would have been saved. At today's prices, these fuel savings would be worth about $4,500 per year to the airlines. It is doubtful that, based on fuel savings alone, the benefits of such a taxiway would outweigh the annualized construction costs. By reducing hold times, however, this option would reduce airline personnel costs and increase passenger convenience. This proposed taxiway addition merits further study by the airport operators.

The Use of Fixed Ground Power Systems

Most of the analysis which applies to using FPS's at DCA applies also at IAD. The capital cost of installing an electrical-only FPS at IAD is estimated to be about $50,000 per gate; the cost of an electrical and pneumatic FPS is estimated to be about $150,000 per gate. The electrical-only FPS is more expensive at IAD than at DCA because there are no gate structures to which the cables can be attached. Instead, the cables would need to be routed under the ramp, at additional cost. Aircraft at IAD are generally larger than those at DCA, so that the demand for pneumatic and electrical power per gate, when the gate is in use, is greater at IAD. This relationship is offset by the lower gate utilization at IAD, which reduces the average per gate demand for electrical and pneumatic power. The cost of electrical and penumatic FPS at IAD is estimated to be $150,000 per gate, which is no more than the cost of such systems at DCA.

The low gate utilization at IAD strongly affects the economics of installing FPS's there. Although United and TWA currently provide fixed electrical power at some of their gates, using GPU's for this purpose is generally a preferrable (in economic terms) short-term solution. Even if an annualized capital cost of $4,070 is assumed for electrical power GPUs, the annualized capital cost of FPS's generally exceeds the sum of the GPU capital cost and the annual savings of using FPS's instead of GPU's (see Table 6.4). For the provision of combined electrical and penumatic power, fixed power systems do not appear to be economically attractive. As can be found in Table 6.4, however, the difference between capital costs and operating savings is not very great. Small changes in the assumptions used could easily produce results more favorable to fixed power.

A more detailed study of the capital cost of installing FPS's at IAD and of the degree to which such systems would be utilized is warranted. By including most or all of the gates at IAD in a single system,

TABLE 6.4

ESTIMATED BENEFITS AND COSTS OF INSTALLING FIXED POWER SYSTEMS AT IAD

(BASED ON 1979 OPERATIONS DATA, 1981 COSTS)

(1981 Dollars)

	ANNUAL OPERATION COST SAVINGS					ANNUALIZED CAPITAL COST		
	ELECTRICAL ONLY		ELECTRICAL & PNEUMATIC			ELECTRICAL ONLY	ELECTRICAL AND PNEUMATIC	
	FPS OVER APU	FPS OVER GPU	FPS OVER APU	GPU OVER APU	FPS OVER GPU	FPS^1	GPU^2	FPS^3
PA	59,072	6,194	52,480	31,985	20,495	26,776	42,476	80,328
TW	62,076	6,188	64,320	52,13	12,189	26,776	42,476	80,328
UA	76,361	7,699	79,599	64,623	14,976	46,858	84,952	140,574
CO	19,900	2,255	22,932	19,110	3,822	20,082	42,476	60,246
NW	46,864	4,448	40,315	26,309	14,006	20,082	42,476	60,246
BN	59,326	6,723	68,364	56,970	11,394	26,776	42,476	80,328
AA	68,625	7,002	72,484	59,060	13,424	26,776	42,476	80,328
AF	3,249	368	3,747	3,123	624	6,694	21,238	20,082
BA	14,714	1,229	13,221	10,258	2 963	6,694	21,238	20,082
RC	15,198	1,722	17,514	14,595	2,919	6,694	21,238	20,082
TOTAL	425,385	43,798	434,976	338,164	96,812	214,208	403,522	642,624

NOTES: [1] \$50,000 pergate, 20 yr lifespan, 12 percent interest.

[2] \$120,000 per unit, 1 unit per 2 gates, 10 yr lifespan, 12 percent interest.

[3] \$150,000 per gate, 20 yr lifespan, 12 percent interest.

TABLE 6.5

COMPARISON OF ANNUAL OPERATION COST SAVINGS MINUS ANNUALIZED CAPITAL COSTS FOR GATE POWER SYSTEMS AT IAD

AIRLINE	POSITIVE SAVINGS (ANNUALIZED SAVINGS > ANNUALIZED K COSTS)			
	ELECTRICAL ONLY		ELECTRICAL AND PNEUMATIC	
	FPS OVER APU	FPS OVER GPU[1]	FPS OVER APU	GPU OVER APU
PA	✓	X	X	X
TW	✓	X	X	✓
UA	✓	X	X	X
CO	X	X	X	X
NW	✓	X	X	X
BN	✓	X	X	✓
AA	✓	X	X	✓
AF	X	X	X	X
BA	✓	X	X	X
RC	✓	X	X	X

Assumes no capital cost for electrical power GPU.

Means positive savings.

X Means no positive savings.

very large economies of scale might be realized. It would be fruitful to consider how the provision of fixed power by the airport might entice the airlines to more fully utilize IAD, thereby increasing gate utilization and making the FPS more cost effective. The possibility of providing pre-conditioned air instead of pneumatic power should also be more closely examined.

Installing fixed power systems at IAD would have a positive environmental impact. It would affect neither present nor future airport capacity. Installing fixed electrical and pneumatic power is a feasible short-term option which is applicable to IAD and many other airports.

VII. IMPLEMENTING CONSIDERATIONS

CATEGORIZATION OF PROMISING FUEL CONSERVATION OPTIONS

Decisions to implement fuel conservation strategies are contingent upon numerous considerations. Costs, benefits, and the number of organizations involved in implementing determinations are major factors to be considered. Other considerations include impacts on safety, airport capacity, noise, air quality, passenger convenience and the time needed for implementation.

The feasibility of implementing fuel conservation strategies was a major concern in the development of options to be considered. The feasibility of procedural and operational strategies was considered in terms of administrative management factors, while airport layout strategies were considered in terms of physical construction possibilities. Strategies were included as feasible options if "they could be done". The fuel savings and activity data are from Chapters V and VI.

The time required to implement fuel conservation options or strategies is an important factor in the decision-making process. Time is a factor of importance in two ways. First, a strategy that is not immediately feasible may be feasible later if existing technology can be expanded or much later if new technology must be developed. Time is also important in that circumstances may change in such a way as to affect the potential benefits to be derived from an implementing decision.

Conservation strategies were classified according to the following definitions of short, intermediate and long term implementation periods:

1. Short Term: These options could be implemented in less than one year and do not require new technology.
2. Intermediate Term: These options could be implemented in one to three years, and/or require expanding existing technology.
3. Long Term: These options could be realized and would be feasible only with development of major technological advances or significant budgetary or political constraints.

Strategies that could, technically, be implemented in one to three years were included in the intermediate term group even when budgetary and political constraints might be expected to delay implementation. This classification strategy was necessary because the definition of long term implementation periods restricts that classification group to options requiring major technological advances.

Costs, where quantified, are included from Chapters V and VI. Strategies were then considered in terms of other budgetary and policy related implementation problems and impacts on safety, the environment, airport capacity and passenger convenience (See Appendix H for greater detail). Finally, strategies were categorized, or ranked taking into account these external factors. The definition of these categories are listed in Table 7.1.

WASHINGTON NATIONAL AIRPORT

Table 7.2 is a summary of implementation considerations concerning promising options for conserving fuel at Washington National Airport. The fuel saving shown for each option is the potential amount that might be saved if no other option were to be implemented.

Three columns are shown to identify the major implementation problems as being budgetary (either labor or capital), policy related, and/or "special". Impacts are designated according to the effects on safety, noise, emissions, airport capacity and passenger convenience as beneficial (+), neutral (0), or adverse (-).

TABLE 7.1

DECISION CATEGORY CLASSIFICATION CRITERIA

CATEGORY I

Options that can produce annual fuel savings amounting to at least 500,000 kilograms and are clearly cost effective.

CATEGORY II

Options that can produce annual fuel savings of less than 500,000 kilograms and are clearly cost effective.

CATEGORY III

Options that appear to be cost effective but involve substantial cost.

CATEGORY IV

Options that do not appear to be cost effective and for which implementation would be contingent upon considerations other than fuel conservation.

CATEGORY V

Options that require further study to determine benefits or to solve implementation problems.

TABLE 7.2

Summary of Implementation Considerations –DCA

Option	Fuel Savings (Kg/Yr)		Implementation Period	Cost ($)	Problems			Overall Impacts	Generally Applicable	Rating Category 2/
					Budgetary	Policy Related	Special 1/			
Procedural										
Computer Aided Paper Queue	7,887,000	Q	IT	Unknown	L&K	✓	✓	+	Yes	V
Manual Paper Queue	3,943,500	Q	ST	150,000	L	✓	None	+	Yes	I
Pre Taxi Engine Start Advisory	1,331,000	P	ST	50,000	L	✓	None	+	Yes	V
Pre Takeoff Engine Start Advisory	900,000	Q	ST	50,000	L	✓	None	0	Yes	II
Maintenance of Unobstructed Taxi Paths	Minimal	T	ST	Minimal	None	None	None	0	Yes	II
Minimization of Start and Stop Actions	Minimal	T	ST	Minimal	None	None	✓	0	Yes	II
Operational										
Less than all Engine Taxi	4,596,267	Σ	ST	0	None	None	✓	+	Yes	I
Minimization of Pre Taxi Engine Operation	665,500	P	ST	0	None	✓	✓	+	Yes	I
Favorable Engine Start Orientation	633,333	T	ST	0	None	✓	✓	+	Conditional	I
Most Direct Taxi Route	250,231	T	ST	0	None	None	✓	–	Yes	V
Minimization of Last Engine Operation	900,000	Q	ST	0	None	✓	✓	0	Yes	II
Optimum Taxi Speed	212,500	T	ST	0	None	None	None	+	Yes	II
Aircraft Towing with Conventional Tow Vehicles	8,500,000	Σ	ST	3,000,000	K&L	✓	✓	+	Yes	IV
Aircraft Towing with Advanced Tow Vehicles	8,500,000	Σ	IT	3,000,000	K&L	✓	✓	+	Yes	IV
Airport Layout Changes										
Electrical Only Fixed Power Systems	2,700,000	G	ST	219,561/yr	K	✓	✓	+	Yes	V
Electrical & Pneumatic Fixed Power Systems	3,100,000	G	ST	823,362/yr	K	✓	✓	+	Yes	V
Taxiway Surface Improvements	950,000	T	IT	17,900,000	K	✓	None	+	Conditional	III
High Speed Turnoff at Taxiway "I"	250,231	T	IT	1,500,000	K	✓	✓	–	Conditional	V
Special Holding Area	Unknown	Q	IT	2,750,000	K	✓	None	+	Conditional	V
Extension of Runways 3 21 and 18 36	Unknown	Q	IT	Unknown	K	✓	✓	–	Conditional	IV

Legend: Activity Code
- Q – queuing
- P – pre taxi, pushback and engine start
- T – taxi
- G – gate

Implementation Period
- ST – short term
- IT – intermediate term

Budgetary
- L – Labor
- K – Capital

1/ Special refers to problems which are airport specific

2/ See page 7-3 for definition

Category I Options

Implementing Paper Queue. The paper queue is the number one opportunity to conserve fuel at Washington National Airport. Table 7.2 shows a 7,887,000 kilogram potential savings for computer aided departure sequencing and half that much, 3,943,500, for a manually operated system. The manual system could be implemented in a short term period and would be expected to require budgeting for increased manpower. The computer aided system would, in addition, require capital expenditures and a longer implementation period (intermediate term). All of the impacts are considered favorable. The difficult problem involves policy, since implementation would be interposing a government operated sequencing system into a very competitive activity.

The manually operated paper queue is given a Category I rating because savings are great relative to costs, and because impacts are beneficial. The computer aided system is given a Category V rating because of the costs and the delayed implementation period, even though savings would be much greater. Either system is applicable to other airports, but the system would have to be tailored to each specific case.

Taxiing with One Engine Shut Down. Taxiing with less than all engines operating is a Category I option because large additional savings would be possible, while implementation costs would be minimal. The estimate that 4,596,267 kilograms would be saved is based upon the assumption that other actions to reduce delay are not implemented. Of course, any option which reduces taxi, hold, and queue time also reduces the potential benefits of less than all engine taxiing. The converse is also true. Even on the margin, however, the less than all engine taxi option is clearly cost effective. The use of this strategy causes no adverse impacts.

Using a Favorable Engine Start Location and Aircraft Orientation. The Category I option to improve aircraft orientation is estimated to result in annual fuel savings of 633,333 kilograms or more, assuming 20 seconds of idle power taxiing could be saved for each departure. Additional savings would accrue from reducing the operation of engines at above idle power during turning maneuvers. Indirect savings would also result if improved aircraft orientation

reduces delays associated with movement of other aircraft along the ramp. A special problem for this option occurs in the south terminal area, where there is barely space for two aircraft in the engine start area. American and TWA pushback crews were observed to delay or slow a pushback and engine start operation to permit a preceding aircraft to complete its engine start process and move out of the area. Additional savings might also be achieved if the aircraft were to be pushed beyond the traffic lane where a favorable taxi orientation would be easier to establish. Ground control should be able to help pushback crews determine when aircraft could or should be pushed farther away from the normal start locations.

There are no adverse impacts associated with implementation of this option. The option is clearly cost effective and is applicable to other airports where aircraft are pushed or towed to an engine start area.

Category II Options

Providing a Pretake-Off Advisory and Minimizing Last Engine Operating Time. The pretake-off advisory procedure to help pilots anticipate an optimum engine start time is clearly cost effective. An operational option to minimize pretake-off operating time for an unstarted engine is also clearly cost effective. Fuel savings were not estimated because of the lack of information concerning present use of the procedure. The advisory procedure should produce greater savings than the operational option. The potential adverse impact associated with either option is the possibility that an aircraft might not be ready when a take-off opportunity occurs. Airport operating capacity would be reduced for each such circumstance. But starting engines too soon would waste more fuel.

Implementation should assume that the selected time increment for engine starts will sometimes cause a 30 to 45 second delay (one operation). Such an impact would be minimal and acceptable.

Maintaining Unobstructed Taxi Paths and Minimizing Starts and Stops. These two Category II options are being used and are important because they are clearly cost effective even though additional savings may be small. The special problems pertain to the generally congested area at DCA.

Increasing Taxi Speed. Table 7.2 shows that 212,500 kilograms of fuel could be saved if only 1 of every 4 aircraft reduces its taxi time 20 seconds by increasing taxi speed. Implementation is subject to pilot discretion and does not impose any special problem. This potential savings assumes no change in runway surface roughness or existing delay situations. The option is generally applicable to other airports although savings are airport specific. It is clearly cost effective and is a Category II option.

Category III Options

Improving Taxiway Surfaces. Improving taxiway surfaces to reduce roughness and permit faster taxi speeds appears to be cost effective with respect to fuel saved over a period of years. This is particularly true when considered in terms of routine rehabilitation needs. The surfaces must be replaced from time to time in any event, and costs and benefits should be considered in terms of the decreased life of surfaces maintained for faster taxi speeds. An intangible benefit results if improved taxiway surfaces reduce adverse stresses on aircraft. The indicated savings of 950,000 kilograms are based upon an estimate that optimum taxi times could be reduced by 30 seconds by improved surfaces. These savings are in addition to those associated with the paper queue.

Application of this option to other airports is conditional upon taxi distances, surface roughness, and delay circumstances.

Category IV Options

Extending Runways. A runway 3-21 extension would reduce delay and conserve fuel, but costs would be great relative to expected fuel savings. An extension at the south end of runway 18-36 would improve the ability of pilots to use the most direct taxi route. An extension to either runway would cost significantly more than 3 million dollars because of airport location and heavy use of runways. Implementation of either option would be highly controversial and would produce adverse impacts in areas where noise would be increased. Delays would still occur and implementation would be contingent upon considerations other than fuel conservation.

Towing Aircraft. The costs of towing aircraft at DCA with advanced or conventional tow vehicles were estimated to be, respectively, 2 or 3 times the value of the fuel which would be saved. Other factors, such as the conjestion and the high capacity utilization, make towing seem even less desirable at DCA. The institution of a paper queue system and the more effective use of the less than all engine taxi strategy would reduce taxi times and fuel consumption sufficiently to cancel out most of the benefits that would have been derived from towing. These options are far more practical at DCA, so towing is an option which, probably, need not be further considered.

Category V Options

Using Fixed Power Systems. Both electrical-only and combined electrical and pneumatic fixed power systems appear to be economically viable options for many of the airlines at DCA. These systems would not only save fuel but would also reduce the airline's ground crew and maintenance costs and improve the ramp environment.

The capital costs of these systems are hard to predict without conducting a thorough engineering survey and without knowing how many gates would be connected to the system. While it seems clear that some alternative to APU's must be found, it is not always clear, especially when considering electrical-only systems, whether the best alternative is using GPU's or FPS's. The above-mentioned uncertainities must be resolved before a rational decision about fixed power can be made. A major study should be conducted in which various scenarios, based upon a variety of assumptions about the type of system installed, the number of airlines and/or gates involved, and the number and type of aircraft which will use the gates in the future, are considered.

Minimizing Pre-Taxi Engine Operation. Large quantities, perhaps in areas of 1 million kg/yr, of fuel are wasted at DCA because of the inefficient pushback, engine start, and commence to taxi procedures used there. Although several operational and procedural strategies for the elimination of this waste were considered (the pre-taxi engine start advisory procedure, for example), no definitive solution was found. There is too much uncertainty about the cause of this waste for a procedure to reduce this waste to be devised. This

uncertainty could be overcome if a fairly simple study of pushback, engine start, and commence to taxi procedures were made. The significant amount of fuel that is being currently wasted warrants such additional study.

Providing High Speed Turn Offs. The high speed turnoff option is shown as Category V because of the high cost and because of the need for additional study to determine conservation benefits. The turnoff should reduce fuel consumption due to delays in the air as well as the 250,231 kilograms consumed because aircraft cannot always use the most direct exit route. Also, additional savings might be attributed to reduced air and ground delays on runway 15-33.

Negative impacts could result due to traffic interactions with ground traffic activity on taxi way K, but airport capacity should be enhanced without adverse environmental impact. Further study of this fuel conservation option is needed.

Using More Direct Taxi Routes. This operational option is placed in Category V. Savings due to its implementation are contingent upon the extent to which pilots can control exit choice. Further study is needed to determine if airport instrumentation, pilot practices or traffic procedures can improve use of direct route exits.

Constructing Special Holding Areas. Special holding areas are not clearly cost effective. Costs are significant and the frequency of need for a place to wait while gates are released for incoming aircraft is not known. Also, the number of times that arriving or departing aircraft might use an unoccupied gate normally used by another airline is not known. Gate use and management practices warrant study to determine fuel conservation opportunities.

DULLES INTERNATIONAL AIRPORT

Table 7.3 summarizes the principle implementation considerations which pertain to each of the promising options for conserving fuel at Dulles International Airport. Estimates of the potential fuel savings accrued from each option were made with the assumption that no other options were implemented. The marginal benefits derived from each additional option generally decline as the total quantity of fuel consumed declines. Therefore, the total potential fuel savings cannot be estimated by simply adding the individual fuel savings for each option.

TABLE 7.3

Summary of Implementation Considerations - IAD

Option	Fuel Savings ($^{Kg}/_{Yr}$)	Implementation Period	Cost ($)	Problems: Budgetary	Problems: Policy Related	Problems: Special 1/	Overall Impacts	Generally Applicable	Rating Category 2/
Procedural									
Manual Paper Queue	400,000 Q	ST(IT)	Minimal	L(L&K)	√	√	+	Yes	II
Pre Taxi Engine Start Advisory	Minimal P	ST	Minimal	L	√	None	+	Yes	II
Pre Takeoff Engine Start Advisory	350,000 Q	ST	Minimal	L	√	None	0	Yes	II
Maintenance of Unobstructed Taxi Paths	Minimal T	ST	Minimal	None	None	None	0	Yes	II
Minimization of Start and Stop Actions	Minimal T	ST	Minimal	None	None	√	0	Yes	II
Operational									
Less than all Engine Taxi	1,733,618 Σ	ST	0	None	None	√	+	Yes	I
Minimization of Pre Taxi Engine Operation	Minimal P	ST	0	None	√	√	+	Yes	II
Most Direct Taxi Route	Unknown T	ST	0	None	None	√	–	Yes	II
Minimization of Last Engine Operation	350,000 Q	ST	0	None	√	√	0	Yes	II
Aircraft Towing with Conventional Tow Vehicles	1,780,917 Σ	ST	3,168,095/yr	K&L	√	None	+	Conditional	IV
Aircraft Towing with Advanced Tow Vehicles	1,780,917 Σ	IT	1,089,079/yr	K&L	√	None	+	Conditional	V
Optimum Taxi Speed	Unknown T	ST	0	None	None	None	+	Yes	II
Airport Layout Changes									
Electrical – Only Fixed Power Systems	750,000 G	ST	214,208/yr	K	√	√	+	Yes	V
Electrical and Pneumatic Fixed Power Systems	750,000 G	ST	642,624/yr	K	√	√	+	Yes	V
Taxiway Improvements	12,000 T	ST	Unknown	K	√	None	+	Conditional	IV

Legend: Activity Code
- Q = queuing
- P = pre taxi push back and engine start
- T = taxi
- G = gate

Implementation Period
- ST = short term
- IT = intermediate term

Budgetary
- L = Labor
- K = Capital

1/ Special refers to problems which are airport specific

2/ See page 7-3 for definition

The next column identifies the implementation period for each option as being short, intermediate, or long term. The cost of implementation is presented in the next column. In the next three columns, the major implementation problems are identified. These problems are categorized as budgetary (either capital or labor) problems, policy related problems, or "special" problems. The aggregate impact of each option on safety, noise and pollutant emissions, airport capacity, and passenger convenience is listed in the next column. The final column shows how each option rates according to the criteria listed in Table 7.1.

Category I Options

Taxiing with One or More Engines Shut Down. Taxiing with one or more engines shut down is the only option which ranks as Category I at IAD. The potential annual fuel savings have been estimated to be over $1.7 million, but the implementation costs would be minimal. Given the high benefit to cost ratio and the absence of adverse noneconomic impacts, the less than all engine taxi strategy should be more effectively used at IAD. A related option, providing a pre-take-off engine start advisory, would improve the effectiveness of this strategy.

Category II Options

The majority of the promising fuel conservation options at IAD are Category II. This is due to the low volume of traffic at IAD which, first of all, limits the total amount of fuel consumed and thus the amount of fuel which can be saved, and, which secondly, limits the amount of hold and queue time and thus the amount of fuel which can be saved by reducing holding and queuing. On the other hand, the low volume of traffic at IAD allows for the informal and inexpensive implementation of many of these options.

For example, the total amount of fuel consumed during holding and queuing activities at IAD is only about 400,000 kg. It is conceivable that, if the tower instituted a paper queue procedure and if the airlines agreed to hold at the gate for departure delays, much of this fuel could be saved. These two options could be instituted very inexpensively at IAD, but their combined impact would remain below 500,000 Kg per year.

Several other options, other than the less than all engine taxi strategy, would reduce the amount of fuel consumed while taxiing. These include increased procedural and operational efforts to minimize start and stop actions, to maintain unobstructed taxi paths, to use the most direct taxi path, and to use the optimum taxi speed. The fuel which would be saved through the implementation of these options would probably not exceed 500,000 Kg per year. Again, however, the implementation costs would be minimal. These options would all have almost imperceptible and generally positive effects on the environment, on airport safety, and on passenger convenience.

Category III Options

None of the promising options at IAD fit the criteria for the Category III ranking.

Category IV Options

Taxiway Improvement. Constructing an additional exit from runway 19L-01R would shorten GA taxi times, reduce air carrier hold times, and result in annual savings of about 12,000 Kg of fuel. It is unlikely that these savings alone would offset the substantial costs of constructing an additional runway exit. When safety, passenger convenience, and airline revenues are considered, however, this option may become cost effective.

Aircraft Towing with Conventional Tow Vehicle. The cost of implementing this option was estimated to be over five times the value of the benefits which would be derived from it. It is unlikely that any side benefits which might be realized through the implementation of this option would outweigh this cost disadvantage.

Category V Options

Aircraft Towing with Advanced Tow Vehicles. By reducing the time penalty associated with towing, the advent of advanced tow vehicles may improve the economics of aircraft towing. These vehicles are currently under development but not yet generally available on the market. When advanced tow vehicles do become available, and when the cost of operating these vehicles is more thoroughly documented, additional study of this option will be warranted.

Using Fixed Power Systems. The principle factor which will determine whether fixed power is a prudent option for IAD is the capital cost of installing the system. It is difficult to accurately estimate the capital cost of a fixed power system without doing a complete study of the airport's power needs at the gates, conducting an engineering study, and knowing how many gates would be served.

It seems clear that, as a short term option, GPU's are cost effective over electrical-only fixed power systems. A comparison of GPU's and FPS's for the provision of electrical and pneumatic power produced mixed results. The results of this comparison were favorable enough, however, that a thorough study of the possibility of installing fixed power at IAD is warranted.

OTHER CONSIDERATIONS

Decision makers face many budgetary and political constraints which could not be adequately considered in the preceding categorization of fuel conservation options. By integrating these considerations with the economic, technical, safety, and environmental considerations which were discussed in this report, airlines and airport managers should be able to develop short, intermediate, and long-term plans for reducing their fuel consumption.

Several factors must be considered as these integrated plans are designed. First of all, the effect that the implementation of one strategy has on the potential savings to be accrued from another strategy must be examined. For example, towing aircraft eliminates the potential benefits to be derived from taxiing with one or more engines shut down. Some strategies,

such as improving taxiway surfaces and using the optimum taxi speed, or constructing high speed turnoffs and using the most direct route, or providing fixed power systems and holding at the gate for departure delays, using a paper queue, are complementary. On the other hand, the implementation of certain options, such as using a favorable engine start orientation, has no effect on the potential benefits to be derived from other options, such as minimizing last engine operating time.

Another factor which must always be considered is the effect that changes in future air traffic activity patterns will have on future fuel conservation efforts. Increased traffic might make some options much more difficult to implement, but also might increase the benefits derived from some options. The converse would be true if lighter traffic were expected. Changes in the fleet mix, for example, from larger to smaller aircraft, would also affect the costs of and benefits derived from some of the promising fuel conservation options. If certain airlines decide to increase or decrease their operations, this would also affect future fuel conservation efforts.

Taking these factors into account, and in cooperation with each other, airlines and airport operators should begin to implement certain promising short term options and should begin to develop complementary intermediate and long term fuel conservation plans. In those areas where additional study will be required by the decision makers, specific questions should be developed, and efforts to answer these questions should be immediately undertaken.

VIII. ANALYSIS OF COMPUTER MODELS WITH SOME CAPABILITY FOR ASSESSING FUEL SAVINGS DURING AIRCRAFT GROUND OPERATIONS

A number of models were reviewed to determine their applicability for assessing fuel savings during aircraft ground operations. The eleven models summarized here are related to some degree to this problem. No attempt is made to place a value judgment on the selection of any of these models for a particular airport application. Potential users are advised to review in greater detail these or other models which might best suit their specific needs.

The models are listed in Table 8.1 and summarized in Table 8.2. They were evaluated according to six criteria.

- Does the model account for all modes involved in the ground operations system?
- Does the model provide measures of the time aircraft spend in the various modes? And does the time in mode vary under different conditions?
- Does the model provide a measure of baseline fuel consumption?
- Is the model capable of identifying and/or evaluating conservation measures such as those evaluated in this report?
- Is the model capable of solving complex fuel conservation problems?

- Does the model provide information about the socioeconomic impact of energy conservation policies?

The models were divided into three categories: those which deal with a single issue such as towing, those which are macro-simulations and work from information on the average times required for various operations,

TABLE 8.1

COMPUTER MODELS EVALUATED

- Aircraft Towing Feasibility Study (Peat, Marwick, Mitchell & Company
- Impact of Aircraft Emissions on Air Quality in the Vicinity of Airports, Vol. I, Vol. II (Argonne National Laboratory and Environmental Research & Technology)
- FAA Airport Emissions Data Base (ORI, Inc.)
- Simulation of Airport Operations (R. Dixon SPEAS Associates)
- Airport Taxiway Model Description (SRI)
- Airport and Airspace Delay Model Description (SRI)
- Guidance in Aircraft and Landside Energy Assessment (Trans System Corporation)
- Evaluation of the Impact of Towing DC-9 (L-1011) Transport Airplanes at Boston-Logan Airport (Douglas) (Lockheed)
- A Proposed Aviation Energy Conservation Program for the National Aviation System (FAA)
- A Study of Aircraft Towing as Proposed for Boston-Logan International Airport (Gellman)
- Models for Runway Capacity Analysis (MITRE)

TABLE 8.2

SUMMARY COMPARISON OF MODELS

SOURCE:							
AUTHOR	PMM.	ANL	ORI	SPEAS	SRI	SRI	TRANSSYSTEM
YEAR	1980	1980	1980	1980?	1980	1979	1979
TITLE	"AIRCRAFT TOWING FEASIBILITY STUDY"	"AIRCRAFT EMISSIONS"	"FAA ENGINE POLLUTION PROGRAM"	"SIMULATION OF AIRPORT OPERATIONS"	"AIRPORT TAXIWAY MODEL DESCRIPTIONS"	"AIRPORT AIRSPACE DELAY MODEL"	"GUIDANCE IN AIRSPACE AND LANDSIDE ENERGY"
USEFUL FOR:							
ENERGY	Y	N	M	M	M	M	Y
CAPACITY	In Ref. 9	N	N	Y	Y	Y	Y
AIR QUALITY	Y	Y	Y	M	M	M	M
NOISE	N	M	M	M	M	M	M
TIME	Y	N	N	Y	Y	Y	N
TRAFFIC MIX	Y	Y	Y	Y	Y	Y	Y
MODEL FORM:							
COMPUTER SIM	N	N	Data File	Y	Y	Y	Data File
COMPUTER SOL'N	N	N	N	N	N	N	N
CLOSED FORM	N	Y	N	N	N	N	Y
GRAPHICAL	N	N	N	N	N	N	Y
OUTPUT FORM:							
COMPUTER DATA	N	N	Y	Y	Y	Y	Y
EXPERIMENTAL DATA	N	Y	Y	N	N	N	Y
TABULATED RESULTS	Y	Y	Y	Y	Y	Y	Y
PARTICULAR AIRPORT	Y(DCA)	Y(DCA, IAD)	Y(DCA)	Y	Y	Y	Y
MODEL DESCRIPTION:							
COMPLETELY DESCRIBED	N	Y	Y	No Desc.	N	N	Y
COMPUTER LISTING	N	N/A	Y	N	N	N	N
EQUATIONS	N	Y	N/A	N	N	N	Y
GRAPHS	N	N	N	N	N	N	Y
COMMENTS	Directly Assumes Time Engines off	Closed Form, 2-Region, Standard Plume Analysis Extremely Poor Correlation with Data	Based on Time Allocation to Each Mode	Only sales Brochures Available Seems Comprehensive	Includes Optimal Taxi Path	Fast Running	Based on Other Simulations or on Trans Savings Estimates

TABLE 8.2 (Continued)

SUMMARY COMPARISON OF MODELS					
SOURCE:					
AUTHOR	DOUGLAS	LOCKHEED	FAA	GELLMAN	MITRE
YEAR	1980	1980	1978	1977	1972
TITLE	"TOWING DC-9 ... LOGAN"	TOWING L- 1011 LOGAN"	"ENERGY CONSERVA-TION PRO-GRAM"	"AIRCRAFT TOWING"	"RUNWAY CAPACITY"
USEFUL FOR:					
ENERGY	N		Y	M	M
CAPACITY	N		N	M	Y
AIR QUALITY	N		Y	M	M
NOISE	N		Y	M	M
TIME	Y		N	Y	Y
TRAFFIC MIX	N		N	N	Y
MODEL FORM:					
COMPUTER SIM	N		N	?	Y
COMPUTER SOL'N	Y		N	N	N
CLOSED FORM	N		N	N	N
GRAPHICAL	N		N	N	N
OUTPUT FORM:					
COMPUTER DATA	N		Y	N	Y
EXPERIMENTAL DATA	Y		N	N	N
TABULATED RESULTS	Y		Y	Y	Y
PARTICULAR AIRPORT	N		N	N	Y
MODEL DESCRIPTION:					
COMPLETELY DESCRIBED	N		N	No Desc.	Y
COMPUTER LISTING	N		N	N	N
EQUATIONS	N		N	N	Y
GRAPHS	N		N	N	N
COMMENTS	Structural-Load Fatigue Model Only; include Effect of Taxiing Speed (pg 3-6 of Lockheed)		Included in Transystems Work	Highly Negative	In-flight Effects Only

TABLE 8.2 (CONTINUED)

LEGEND

1. The model is indicated as useful for various studies according to whether a Y is listed (yes), an N (no), or an M (with modification).

2. Whether the model is a computer simulation, a computerized solution to mathematical equations, a closed-form mathematical solution, or a graphical solution is presented in the next section of the summary chart.

3. The form of the output can be in terms of computer data -- either a compendium of data or a tabulation of computed output; experimental data as used in developing an empirical model; tabulated results as typed for the report. If the output is suitable for use at a particular airport with known traffic pattern is also indicated. If DCA or IAD were considered in the particular report is also indicated.

4. The available model descriptions varied considerably, ranging from a Speas sales brochure to the MITRE mathematical equations. If the mathematics were presented, the description was judged complete (Y, for yes). If the description were in prose only, the description was judged as absent (N, for no). If vague words or no words were used to describe the model, "NO DESCRIPTION" was entered. A computer listing would be considered the most defined of all forms -- although they frequently contain disabling errors. If the model was described in terms of equations which were not necessarily used in the computer, a Y was entered on the line marked "EQUATIONS". If graphical output was the only form, so the model was described by graphs, a Y was entered on the next-to-last line.

and those which are micro-simulations and work from simulations of the movements of individual aircraft. In view of the limited usefulness of the first category, attention was focused on the last two categories. Following an analysis of the available literature on each of the models, a questionnaire was then developed and used as a guide to obtain supplemental information. The results of this questionnaire are shown in Appendix I.

Two models were the› selected for review in detail. Each was chosen because it was considered the most useful model of its type. The first model reviewed in detail was the SRI Taxi Model. This model, currently under development, represents the state-of-the-art among models which simulate individual aircraft movements from final approach to gate and back through take-off. The SRI model was studied to determine its ability to resolve complex fuel conservation problems at a particular airport. Other models of this type include the Speas model, also available through Aviation Simulations International, and the delay simulation model (DSM) developed for the FAA by Peat, Marwick, Mitchell & Company.

The second model reviewed in detail was the FAA Aircraft Engine Emissions model, henceforth referred to as the ORI model. This model has a well developed data base which includes twenty-six commercial airports and thirteen general aviation airports. The main advantage of this type of model is its ability to provide estimates of aggregate fuel consumption associated with alternative ground operations for a large number of airports including all of the major commercial airports in the United States. The other model of this type was used in the Trans Systems study of landside energy use.

SRI TAXI MODEL

The SRI Taxi Model is a micro-simulation model which tracks the movement of each aircraft from landing to gate and back to take-off. The airport is represented as a large set of links and nodes, each of which can accommodate one aircraft at a time. The model is designed to provide an estimate of the reduction in delay and increase in capacity that could be gained from an optimal assignment of taxipaths. The model incorporates algorithms which optimize path selection in the sense that time from touchdown to gate stop (or gate to take-off) is minimized. The model can be run in a non-optimizing mode to simulate movements along pre-assigned taxi paths.

The model is also designed to provide information on the fuel consumption associated with each stage of the landing to take-off cycle. The fuel consumption algorithms are being developed by the METREK division of the MITRE Corporation.

ORI AIRCRAFT ENGINE EMISSIONS MODEL

The ORI Aircraft Engine Emissions Model is a macro-simulation model. The data base contains information on fuel consumption rates for each engine in each segment of the landing take-off (LTO) cycle. It also contains information on times for each mode of the LTO cycle specific to aircraft types and airports. The model contains information for all of the major aircraft engines in current use as well as auxiliary power units and ground service vehicles. The model was designed to provide information on pollutant emissions associated with alternative regulatory scenarios. Because the model was designed for this purpose, it can be readily modified to provide information on fuel consumption associated with alternative scenarios.

EVALUATION OF SRI AND ORI MODELS

Both models contain a comprehensive list of the modes involved in the landing take-off cycle. The SRI model is more detailed in terms of the sequence of physical locations through which the aircraft pass. The ORI model uses historical taxi data provided by the FAA.

The SRI model provides partial information on how mode times vary under different conditions. Specifically, the duration of holds at the start of the runway, taxi-time and the number of and duration of stops at nodes along taxiways and runways are simulated for each aircraft passing through the airport. These variable mode times are affected by the number of aircraft placing demands on the limited capacity of the airport at the time in question. Times in these modes may be aggregated by airline or aircraft for any time period desired. It is interesting to note, however, that time in modes is strictly a function of hold times since taxi speeds are assumed to be constant for all incoming and outgoing aircraft, regardless of traffic density or aircraft mix. Thus, the model may provide inaccurate estimates of actual hold time versus time in motion. Such a distinction may be important if fuel consumption rates differ between these

two modes, as they typically would if taxiing with one or more engines shut down.

Other mode times such as gate operations, pushback and engine starts are not allowed to vary and are inputs to the model.

The ORI model uses data fields which specify taxi times by type aircraft. The model could therefore be readily modified to include the effects of airport congestion on average cycle times in peak hours by adding an additional field.

Both models have the capability to provide information on baseline fuel consumption. In each case, aggregate airport fuel consumption is derived from information on fuel consumption rates for each segment of the taxi cycle for each type of engine. In the case of the SRI model, the aggreation is across individual aircraft. In the case of the ORI model, the aggregation is across types of aircraft.

The ORI model was not designed to aid in identifying means of conserving fuel whereas the SRI model is designed to find optimal taxipaths and minimize delay times. Use of the most direct taxi route from touchdown to gate has the effect of conserving fuel.

Both the SRI and ORI models have a capability to quantify the fuel savings that can be realized from implementation of the conservation measures.

The SRI model can be used to "experiment" with alternative airport layouts such as additional gates or altered taxiways. Such "experiments" involve changing the inputs to the model. The model is designed to identify the optimal set of alternatives. Both the SRI and ORI models can be modified to allow for parametric changes in fuel consumption rates for each segment of the landing take-off cycle for each type of aircraft in common use. The new fuel consumption rates would be those associated with taxiing out or in with one or more engines shutdown and/or taking off carrying only the amount of fuel actually needed and/or substituting a ground power unit or the aircraft's auxiliary power unit for aircraft engines during extended holds. The fuel consumption rates associated with these conservation measures must be obtained from other sources.

They may readily serve as inputs into the models but they are not outputs of the models. The SRI model can be used to "experiment" with alternative airport layouts such as additional gates or altered runways. These changes involve changing inputs to the model.

The ORI model can be readily modified to allow for the parametric changes discussed above. The model is already set up to compare a limited number of scenarios. Modification of the SRI model to allow for parametric changes would be a much larger undertaking because of the complexity of the model and because the model was not designed to allow for "experiments" with alternative operations. Alteration of airport layout is an exception. Such experimentation is fairly easy with the SRI model.

Neither model has the ability to solve complex conservation problems. The SRI model can solve the taxiway assignment problem but conservation problems are broader than this. They involve trade-offs between alternate power sources, alternate hold positions, alternative gate assignments, alternate load factors, etc. as well as alternate taxiway assignments.

The fuel consumption component of the SRI taxi model being developed by the METREK division of The MITRE Corporation, may provide insight into the energy required for ground operations. Knowledge of energy requirements, together with knowledge of alternative power sources and their fuel consumption rates will be useful in the development of a model capable of solving complex fuel conservation problems.

The ORI model is a descriptive macro-simulation. The model cannot be used to solve for optimizing bahavior.

The SRI model does not provide information on the socioeconomic impact of conservation efforts. The ORI model is designed to provide detailed information on the oxides of nitrogen, hydrocarbon, and carbon monoxide emissions at airports generated by aircraft engines, auxilliary power units, ground service vehicles and hydrocarbon evaporation from a variety of sources. This information would be provided for every alternative considered.

The main drawback of the SRI model is that the simulation of each aircraft and each mode and link is necessarily inefficient and expensive. This is so because events in the progression of the aircraft through the airport occur very frequently and a large number of such events are occurring simultaneously causing the simulation to advance slowly. This drawback is shared by other micro-simulation models. Such models are appropriate only when a very detailed analysis of ground operations is desired.

POTENTIAL OF THE SRI TAXI MODEL

The SRI model is the most advanced model of its type. However, it is limited in that it does not include many operational alternatives relevant to fuel conservation. The model does not allow for delaying engine starts, landing roll, fuel load planning, strategic gate holds, towing or taxiing with some engines shut down. The model does not allow for optimal ground control except in the assignment of taxipaths. Nor does it allow for remote parking, portable lounges or paper queues. Some of these shortcomings may be overcome by modification of the model, as noted in the following discussion.

Possible Modifications

After modification, the SRI model could be very useful in solving many of the ground operations scenarios to minimize fuel consumption. The model could then be used to simulate experiments. In this way, it would be useful in determining a solution to many of the energy conservation problems.

Modifications are of two types: those which require the development of new algorithms and those which do not.

Minor Modifications:

- Gate time could be increased at all gates to simulate gate hold.
- Startup, warmup, checkout time and associated fuel consumption could be added (assuming one occurance and assuming that time used is a constant).

- Taxispeed could be reduced for all taxiways and aircraft to simulate towing and rolling landings.
- Hookup and APU times could be added assuming they are constants.
- Additional gates could be added for simulation. These could serve as proxies for remote parking.
- Runways could be added or lengthened for simulation.

Major Modifications Requiring New Algorithms:

- Selective gate holds.
- Selective reductions in taxi speed.
- Paper queues and remote parking.
- Selective engine shutdown during queues.
- Variable hookup and APU times.
- Selective use of remote lounges.

OTHER MICRO-SIMULATION MODELS

Most of the other micro-simulation models are similar to, but generally inferior to, the SRI model.

All of the models contain a comprehensive list of the modes assumed by the aircraft in the landing take-off cycle and all provide estimates of the time aircraft spend in the various modes under varying crowding conditions. However, only one model in addition to the SRI taxi model presently provides information on baseline fuel consumption. This is the ASM-2 model developed by R. Dixon Speas Associates under the direction of Everett S. Joline. This model estimates fuel consumption by assuming that all engines are on and idling from pushback to take-off. Given these same assumptions, the other models could be readily modified to provide estimates of fuel consumption since such consumption would be a simple linear function of time from pushback to take-off. ASM-2 and other simulation models would have to be substantially redesigned before they could provide detailed information about the fuel consumption associated

with alternative measures designed to conserve the fuel consumed in ground operations.

The models, with one exception, simulate a sequence of events represented by delay times at rodes roughly 300 feet apart and movements at predetermined constant speeds between nodes. The models do not simulate aircraft movements in time. Actual stops and starts and accelerations and decelerations are not simulated. To our knowledge no attempt has been made with any of the models to compare the observed number of stops and starts at particular airports with the number estimated by these models. The discrepancy, if significant, could be corrected by altering the number and location of nodes.

Correct estimation of stops and starts may be needed in comparisons of alternatives such as take-off queues, paper queues, towing and taxiing with one or more engines shut down. Correct estimates are important because energy must be expended to overcome static friction and this expenditure of energy may affect fuel consumption for one or more of the alternative sources of power.

The one exception appears to be the ASM-2 model. This model has a post-processor and motion picture plotting routine which computes and records the position of each aircraft once every second. The model does not require segmentation of taxiways into nodes and links. Instead segmentation of runways and taxiways correspond to actual endpoints, curves and intersections. Segment capacity is a function of aircraft characteristics such as size and average acceleration-deceleration times. This model does simulate aircraft stops-starts and accelerations-decelerations, according to its developers. Therefore, ASM-2 appears to have some of the features which may be useful in comparing conservation programs. While the ASM-2 model appears to have certain desirable characteristics it should be kept in mind that the information available to reviewers is quite limited and vague consisting of a sales brochure and a brief technical paper. While ASM-2 appears to be a powerful simulation model with much potential, a conclusive evaluation cannot be made on the basis of the information currently available.

A comparison of the salient features of the ORI and SRI models is shown in Table 8.3.

TABLE 8.3

COMPARISON OF THE ORI AND SRI MODELS

	SRI	ORI
Comprehensive list of modes	Y	Y
Time in modes	Y	Y
Under varying conditions	P	P
Baseline fuel consumption	Y	Y
Conservation techniques		
Identification	P	N
Quantification	P	P
Solutions to Complex problems	P	N
Information on socio-economic impact	N	P
NOTES:	A micro simulation under development applied experimentally to three airports	A macro simulation already in place applied operationally to 39 airports

LEGEND: Y = Yes
P - Partial
N - No

IX. CONCLUSIONS AND SUGGESTED AREAS FOR ADDITIONAL STUDY

Principal conclusions developed during the investigation of fuel conservation practices or procedures implemented by airlines or the government at IAD and DCA are as follows:

- Both the government and industry have published fuel conservation practices and procedures to reduce fuel consumption during ground operations. The extent to which these procedures and practices are implemented is in doubt, however, as evidenced by conflicting information received during interviews with airline/tower operating personnel and data collected during on-site visits to DCA and IAD airports.
- Of the scenarios evaluated, taxiing with less than all engines would save the largest amount of fuel. The second most fuel conservative practice would be to use the most direct route when taxiing to the gate after landing. Starting engines during pushback at DCA has a potential savings of 381,015 kg; however, observed data revealed insufficient time was saved to realize any fuel savings. In fact, the practice resulted in excess fuel being used to expedite taxi by an average of 15 seconds.
- Holding at the gate to avoid airborne delays is a definite fuel savings procedure and is directly related to the length

of the delay. An appreciation of the potential fuel savings were shown by the variations in consumption rates for the different power sources.

- Fuel load planning has an insignificant impact on fuel conservation during ground operations unless combined with the less than all engine taxi procedure. In this event, it would be necessary to increase the power on the remaining engines and hence detract from the potential savings.

- A prioritized list of the options and costs saved (in 1979 dollars) are shown in Table 9.1.

Based on the review of current models and a special assessment of the potential of the SRI taxi model, it is concluded that current models are of limited usefulness as analytical tools.

AREAS FOR ADDITIONAL STUDY

The ORI investigation of fuel conservation practices and procedures during ground operations at DCA and IAD identified a number of fuel conservation opportunity areas that warrant additional study. The objective of these studies would be to obtain knowledge that is not presently available and/or to explore implementation problems as well as their impact on aircraft demand factors such as gate utilization, holding areas and effect on arrival delays. These study areas are discussed in this section.

Departure Sequencing for Paper Queue

Problem. Computer aided ground traffic sequencing systems for high density traffic airports appear to offer an attractive opportunity to minimize fuel consumption on such airports. A manual system would be helpful, but the computer aided system could operate with a smaller planned departure delay. The manual system was estimated to enable a savings of 3,943,500 kilograms of fuel per year. A computer aided system could save twice as much fuel or 7,887,000 kilograms per year. Additional savings should be possible to the extent that either system results in a more efficient management of arrivals and departures.

TABLE 9.1

PRIORITIZED LIST OF FUEL CONSERVATION PRACTICES

DCA		IAD	
Fuel Conservation Practice	Potential Savings (1979$) [1/]	Fuel Conservation Practice	Potential Savings (1979$)
(1) Taxi using less than all engines	827,418/yr	(1) Taxi using less than all engines	314,109
(2) Use direct routing	45,042/yr [2/]		
(3) Start engines during pushback	68,583/yr		
(4) Use gate hold procedures	Up to $4/minute of engine use saved		
(5) Fuel load planning	Insignificant		

1/ Calculations were based on 1979 operations data and on an average 1979 fuel cost of 18¢/kg.

2/ These are additional savings that could be achieved.

Recommendation. A manually operated sequencing system should be implemented on an experimental basis for peak hour traffic periods. This will require the support of tower personnel and airline operators.

FAA's Task Force Study of Washington National should be expanded to explore costs and benefits of a computer aided ground traffic system at DCA. The study could impose manpower and budget problems on the FAA Technical Center.

Less Than All Engine Taxi

Problem. The coefficient of rolling friction varies with the seasons for some surfaces (asphalt) and is not the same for every airport. The coefficient varies from 1.3 percent to at least 2.0 percent. The result is a substantial variation in power requirements to taxi that can be as much as the idle power of one engine. Accurate assessment of the less than all engine taxi option is complicated by the lack of information concerning this coefficient.

Recommendation. Tests should be conducted to measure coefficient of rolling friction for representative airport surfaces and aircraft. Information can be obtained in three ways:

a. Obtain measurements with a fully instrumented aircraft.

b. Make arrangements with airline pilots to observe and record power settings needed to maintain approximately constant taxi speeds at known takeoff weights during scheduled departures (this is a data of opportunity effort).

c. Make arrangements with airlines and airport authorities to observe the rate of change of taxi speed with time for known departure weights as aircraft taxi while using idle power. An airport vehicle would be used to determine taxi speed at various times as both vehicles move together along taxiways.

Recommendation "a" is the most difficult and expensive test program. Adequate accuracy could be obtained by either recommendation "b" or "c", which could produce data for a number of airports and seasons with small costs.

Cockpit and Tower Workload

Problem. A workload analysis is warranted to evaluate the time and coordination of activities affecting taxi time. Whereas safety has generally been the prime consideration used to establish cockpit and tower procedures, there is now a need to also focus attention on fuel conservation. Since taxi, hold and queue time directly affect fuel consumption, methods of improving taxi, hold and queue efficiency should be sought. Each 10 seconds saved during departures at DCA results in a fuel savings of 208,526 kilograms per year.

Recommendations. Conduct a time and motion analysis of pilot and controller activities as they affect taxi, hold, and queue time.

Aircraft Taxi Speeds

Problem. Estimates of optimum taxi times at any airport are affected by the accuracy of taxi speed estimates for taxiway segments. Accuracy could be improved if taxi times could be observed for aircraft as they negotiate various layout configurations, such as sharp, 90° degree or 45° turns. Rates of acceleration to taxi speed are also important because of the effect they have on power and fuel requirements. Also, some aircraft taxi at slower speeds to reduce temperature build-up in tires. Accuracy of the method developed by ORI for estimating fuel use and conservation strategy benefits at various airports would be improved if this information could be made available.

Recommendations. Data should be obtained concerning the time needed for aircraft to negotiate a variety of airport layout taxi way configurations and segments. Observations should be obtained for a representative sample of airports and layout situations.

Implementation requires manpower to observe operations and to measure and record taxi times. Airline identity should be retained with the observations to determine how airline policy affects taxi speed for the same aircraft type.

Highspeed Turn-Off and/or Runway Extension at DCA

Problem. A high speed turn-off and an extension to the south end of runway 3-15 at DCA each offer capacity improvements that could reduce delay on the airport and fuel used for landing and departure activities. Either proposal would be highly controversial but should not increase or change the number and types of aircraft using the airport, since these are regulated. The high speed turn-off would be less controversial. The benefits from either change are different depending on traffic mix and the number of operations.

Recommendations. The FAA Task Force study of DCA should be revised to include investigation of airport layout changes including a high speed turn-off and a runway extension.

Fuel Conservation Task Force and/or Briefing

Problem. Interviews with pilots, controllers and airline ground personnel indicated significant interest in fuel conservation. Personnel often thought that some one else could do something to save fuel or lacked information concerning the impact of their activities on another activity. They sometimes throught that implementation of a good idea was blocked by some policy or technical problem, when in fact, such problems might not really exist.

Recommendation. Briefing material should be prepared and a task force established for joint meetings with personnel and management involved in the various activities affecting aircraft fuel conservation on airports. The purpose of these meetings should be to:

a. Improve fuel conservation.

b. Insure that activity interfaces to not unnecessarily waste fuel.

c. Acquire additional information.

d. Improve fuel conservation consciousness and morale.

Fixed Power Systems

Problem. Though the full savings which would accrue from the use of fixed power systems at IAD and DCA are great, the economic superiority of these systems over continued use of APU's or over increased GPU use is not totally clear.

Recommendation. The airport managers and airlines at IAD and DCA should discuss the possibility of installing airport-wide or smaller fixed power systems. Interested parties should participate in detailed engineering assessments to estimate the probable costs of installing fixed power systems. These costs should then be compared with the savings that are expected to result from using such systems.

APPENDIX A

FIELD DATA COLLECTION PROCEDURES

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APPENDIX A

FIELD DATA COLLECTION PROCEDURES

This appendix describes the methodology used by the ORI team to collect aircraft taxi times under varying operational and meteorological conditions at IAD and DCA airports. The methodology is explained in terms of data requirements, personnel and equipment needs, data form entry instructions, and follow-up actions.

DATA REQUIREMENTS

The purpose of the data collection effort was to obtain disaggregated taxi times (including time spent taxiing, waiting in queues and holding at control points) for those aircraft and airlines which operate at DCA and IAD airports.

Data elements considered of primary interest were:

- Taxi times during periods of:
  - IFR and VFR meteorological conditions
  - Peak and non-peak traffic conditions
  - Weekday and weekend traffic conditions.
  - Day and night operating conditions.
- Runway, taxiway and gate position used
- Airline/aircraft designation

- Disaggregation of total taxi time by time spent during pushback, taxiing, waiting in queues, holding (to include the total number of complete stops) as well as total taxi time.
- Other factors, such as when aircraft engines started (e.g., during pushback), when a gate had to be released for incoming traffic, and any other unusual occurrence.

PERSONNEL AND EQUIPMENT

Preliminary to the actual on-site data collection it was necessary that a qualified team be assembled, equipped and trained. It was important that the team have an understanding of the airport layout and be able to identify those aircraft which operate at the airports of interest. In preparation for the data collection, ORI prepared detailed airfield layouts, clearly marking the active runways, numbering the runway turn-off positions and arrival/departure gates. Where feasible, the airlines using specific gate positions were also noted. In addition to the airfield layouts, aircraft recognition manuals were prepared and studied. These manuals contained pictures, salient identification features of the aircraft and the airlines which use that type of equipment. After the team considered themselves adequately prepared, a meeting was scheduled with the airport/tower managers to introduce the ORI team, accomplish administrative requirements (clearance to the tower, parking of private automobiles, etc.), obtain an orientation of the tower and access to a radio receiver to listen in on ground control.

It was determined a crew of two personnel was sufficient to observe the traffic at IAD; however, because of the heavier traffic at DCA, a third person was added to the team. For a two member crew one person observed all inbound and the second all outbound aircraft. When there was a third person, the first two observed only the air carrier traffic while the third observed the air taxi and general aviation traffic.

In addition to the equipment mentioned above, each team member reported to the air field with the following equipment:

- Digital watch
- Binoculars

- Clipboard
- Data forms (described below).

DATA FORMS

Data forms were prepared for each airport with annotated field layouts at the top for easy reference (see Tables A.1 and A.2). The remainder of the form was arranged such that the observer could enter the data for ease in data collection.

Specific instructions for completion of the data collection forms were as follows:

- Prior to beginning observations the observer was to fill in the top portion of the data form - observers name, date, wind speed and direction, IFR or VFR meteorological conditions and beginning time of observation.
- For each aircraft observed, the team member was to note whether it was inbound or outbound, the aircraft category (air carrier, air taxi or general aviation), the air carriers name and aircraft type. It was also important to note the number of engines on the aircraft in case there was confusion as to the proper airline/aircraft designation.
- Inbound traffic notations consisted of the runway used, the time the aircraft departed the runway, the point at which the aircraft left the runway, and its final destination (gate). Notations were made for all delays encountered by the arriving aircraft (holds at control points or waiting for a gate). In addition, if the aircraft shut down one or more engines enroute to the gate it was so noted.
- For outbound traffic the observer noted the departure gate and route to the active runway. If the aircraft made a midfield departure it was so noted. Also collected was the time spent during pushback, all hold times and the time spent in queues. In addition, the collectors were to note whether the aircraft

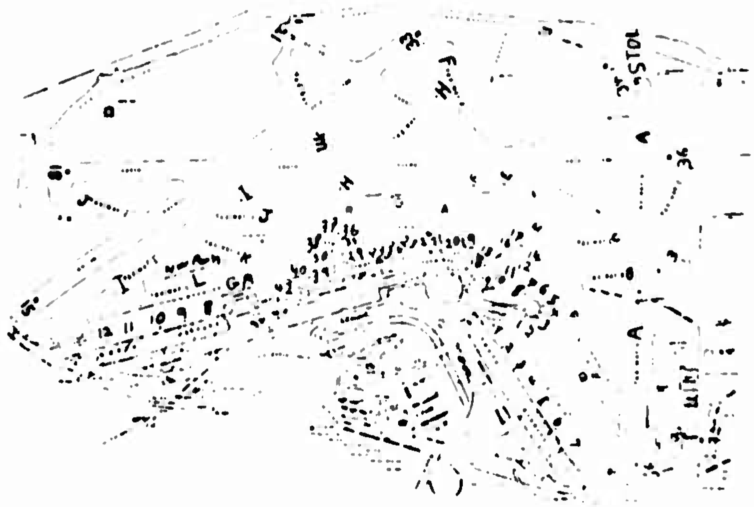
TABLE A.1

DATA FORM DCA

Observer H. Hilliard WS 0 WD [illegible]

Date Sunday 11/23/80 [illegible] [illegible] X

Time from 11:12am To 12:50 pm



IN/OUT AC, MIL or GA	No Engines Opera-tional	Aircarrier, Flight # & A/C Type	R/W # & TXW # or Gate #	Time A/C Leaves R/W or Gate	Taxi Until	Hold At	Hold Until	Taxi Until	Hold At	Hold Until	Takeoff or Gate stop time	R/W or Gate #
Out AC	2	HNA Short	Commut.	11:13:00	13:40	2nd 15	13:59				11:13:59	15
Out GA	1	Cherokee	Butler	11:15:15	16:20	endL	16:40				11:17:00	15
Out GA	1	C-172	NW Pkg	11:15:18	16:20	endL	16:40	16:55	end15	17:40	11:17:40	15
Out GA	2	HNA Short	Com. Ter	11:22:00	23:25	end15	23:36				11:23:36	15
In GA	3	JengFalcon	18-G	11:33:18							11:35:23	Butler
Out GA	3	JengFalcon	Butler	11:39:20	40:40	K&15	11:19	42:22	end18	44:50	11:45:12	18
IN GA	2	Citation	18G	11:40:20							11:42:33	Butler
IN GA	2	Falcon	18G	12:11:06							12:13:48	Butler
Out AC	4	AL DH-7	Com Ter	12:17:44							12:19:25	15
Out AC	2	UN B737	29	Push 12:20:45	22:40	near gate	23:20				12:24:14	18
Out GA	2	Citation	Butler	12:23:05							12:25:43	15
Out AC	2	PI B737	30	Push 12:25:35	26:50	near gate	28:17	30:50	end18	33:25	12:33:25	18
Out AC	3	UN B727	29	Push 12:29:15	30:30	near gate	31:01	33:52	end18	34:20	12:34:20	18
Out AC	2	Pn DC-9	5	Push 12:31:50	32:46	near gate	33:40	38:06	end18	38:46	12:38:46	18
Out GA	1	Cherokee	Butler	12:34:15	36:20	tywL	39:33	38:50	end15	39:15	12:39:15	15
Out AC	2	AimechB99	Com Ter	12:35:10							12:37:25	15
Reposi.	0	UA B-727	S Hangar	12:40:30	tow						12:42:40	18

TABLE A.2

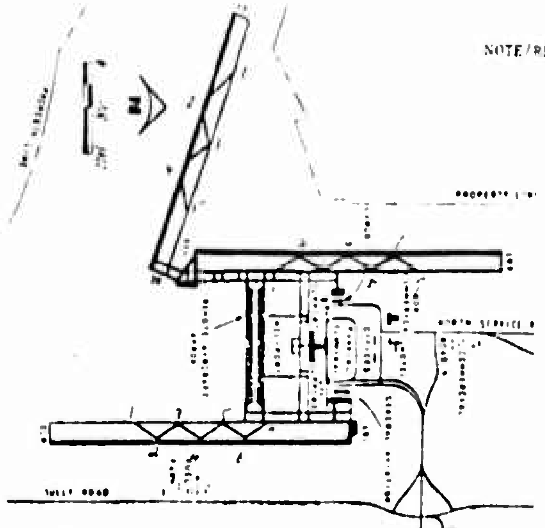
DATA FORM IAD

Observer: A. Hilliard W/S 5 WD 360

Date: Sunday 11/9/80 Remarks: Just returned to VFR condition

Time from 3:59 pm to 5:25 pm Serial No. ____

NOTE/REMARKS:



Mode of Taxi: Number and % of Engine shut down by airlines..
Dulles: due to short distance, all engines are on..

Reverse for note:

IN or OUT	No Engines Operational	Airlines, Flight # A/C Type	R/W and T/W	Time (calculate elapsed)	Taxi Time/Segment 1	Taxi Time/Segment 2	Taxi Time/Segment 3	Hold Time Segment 1	Hold Time Segment 2	Final Position Time	Position Gate or R/W
Out GA	4	Jet Star	Page	4:01:00				0530-0600		4:06:00	19L
In AC	3	UN DC-10	19R-2	4:02:58						4:06:30	Mid East
Out GA	1	Cherokee	SE Park	3:10:40				1040-1550	1920-2025	4:22:25	19L
In AC	3	TWA L1011	19R	4:17:56						4:24:40	Mid East
Out GA	2	G2	Page	4:18:08				1800-2120	2400-2535	4:25:36	19L
In AC	3	AA DC-10	19L-2	4:23:47						4:27:50	West
Reposi.	1	Cherokee	SE Park	4:26:30						4:28:50	Page
In AC	4	UN DC-8	19R-2	4:31:50						4:36:40	Mid
Reposi.	1	C-172	SE Park	4:50:20						4:54:40	Page
out GA	1	Grumman	Page	4:52:00				5320-5600		4:56:53	19L
Out GA	1	Cherokee	SW Park	4:56:10				5635-0200		5:02:50	19L
Out GA	2	Citation	Page	5:02:50					0834-1127	5:11:27	19L
Out GA	1	C-150	Page	5:09:50					1115-1225	5:12:55	19L
In GA	2	Aztec	19L-6	5:15:45						5:18:34	Page
Out AC	4	UN DC-8	Mid W.	5:19:20					2523-2830	5:29:00	19L
In AC	2	Col8E99	19L-6	5:19:30						5:22:30	Tower
Out GA	2	Aztec	Page	5:20:34				2034-2220	2530-2740	5:27:28	19L

started their engines during pushback or taxied out on less than all engines. Taxi time was considered complete when the aircraft took the active for take-off.

FOLLOW-UP ACTIONS

At the close of each day's collection efforts, the material was reviewed to assure that a representative sampling of taxi times had been collected by airline/aircraft type under various operating and meteorological conditions. If data gaps were noted, additional collection effort was scheduled. Based upon the lessons learned during the collection efforts at IAD, a slight modification was made to the data form used for DCA.

Data was recorded for both taxi-out and taxi-in operations by airline and aircraft type for each airport.

Once the raw data was collected, it was aggregated by airline and summarized by aircraft type in the following manner: by visibility conditions (IFR, VFR); by peak/non-peak activity periods; and by runway used. This enabled the project team to analyze the taxi times during ground operations under a variety of operational and meteorological conditions. Each of the times was then further disaggregated by the type of ground operations, e.g., taxiing, holding, waiting in queues and repositioning. Taxi routes used by each of the airlines were also recorded as well as the location that the holding and queuing took place. This information on taxiing and holding was used to compute the baseline estimate. A complete set of the aggregated data is contained in Table A.3 for DCA and Table A.4 for IAD.

In addition to collecting taxi time data, the ORI team also made observations of actual operating procedures. These observations included pushback times and engine start procedures, i.e., at what time did the aircraft start their engines (before pushback, during pushback or after pushback was completed)?

TABLE A.3

CONSOLIDATION OF TAXI TIMES DCA																	
			36		18		33		15		03		21				
	AIRLINE*	TYPE AIRCRAFT	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	AVG
T	AA	B727	2:31	4:04	8:19	2:02	-	-	-	-	-	-	-	-	5:25	3:03	4:14
M			2:18	:06	1:08	:04	-	-	-	-	-	-	-	-	1:43	:05	:54
Q			:12	-	:25	-	-	-	-	-	-	-	-	-	:18	-	:09
Σ			5:01	4:10	9:52	2:06	-	-	-	-	-	-	-	-	7:26	3:08	5:17
T	BN	B727	2:47	2:07	3:51	1:58	-	2:58	3:08	-	3:12	-	-	-	3:55	2:21	2:48
M			:54	-	3:06	:02	-	-	1:12	-	1:50	-	-	-	1:45	:01	:53
Q			:23	-	10:33	-	-	-	1:04	-	-	-	-	-	3:00	-	1:30
Σ			4:00	2:07	17:30	2:00	-	2:58	5:24	-	5:02	-	-	-	8;00	2:22	5:11
T	DL	B727	4:24	2:28	3:31	2:28	1:58	-	-	-	-	-	-	-	3:18	2:28	2:53
M			1:02	:02	2:14	-	1:06	-	-	-	-	-	-	-	1:27	:01	:44
Q			-	-	8:00	-	-	-	-	-	-	-	-	-	2:40	-	1:20
Σ			5:26	2:30	13:45	2:28	3:04	-	-	-	-	-	-	-	7:15	2:29	4:57
T	EA	B727	6:03	3:16	4:36	1:52	-	-	3:52	-	3:18	-	-	-	4:27	2:34	3:30
M			1:12	:06	:59	:22	-	-	2:46	-	:42	-	-	-	1:25	:14	:50
Q			:08	-	1:22	-	-	-	-	-	-	-	-	-	:23	-	:12
Σ			7:23	3:22	6:57	2:14	-	-	6:38	-	4:00	-	-	-	6:15	2:48	4:32
T	NA	B727	-	2:48	2:34	-	-	-	-	-	-	-	-	-	2:34	2:48	2:41
M			-	-	3:18	-	-	-	-	-	-	-	-	-	3:18	-	1:39
Q			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Σ			-	2:48	5:54	-	-	-	-	-	-	-	-	-	5:54	2:48	4:20
T	NW	B727	3:14	4:48	6:24	3:02	-	-	-	-	-	-	-	-	4:49	3:55	4:22
M			1:10	:06	:52	-	-	-	-	-	-	-	-	-	1:01	:03	:32
Q			-	-	:14	-	-	-	-	-	-	-	-	-	:07	-	:04
Σ			4:24	4:54	7:30	3:02	-	-	-	-	-	-	-	-	5:57	3:58	4:58
T	PA	B727	4:08	1:52	2:56	2:22	-	-	-	-	-	-	-	-	3:32	2:07	3:50
M			1:22	-	2:20	:05	-	-	-	-	-	-	-	-	1:51	:02	:56
Q			-	-	1:56	-	-	-	-	-	-	-	-	-	:58	-	:29
Σ			5:51	1:52	7:11	2:27	-	-	-	-	-	-	-	-	6:21	2:09	5:15
T	UA	B727	-	4:22	1:53	-	-	-	-	-	-	-	-	-	1:53	4:22	3:08
M			-	:28	3:02	-	-	-	-	-	-	-	-	-	3:02	:28	1:45
Q			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Σ			-	4:50	4:55	-	-	-	-	-	-	-	-	-	4:55	4:50	4:53
T	TW	B727	4:21	3:56	5:38	2:20	-	-	-	-	-	-	-	-	5:00	3:08	4:04
M			2:32	:05	1:13	-	-	-	-	-	-	-	-	-	1:52	:02	:57
Q			:25	-	:46	-	-	-	-	-	-	-	-	-	:36	-	:18
Σ			7:18	4:00	7:38	2:20	-	-	-	-	-	-	-	-	7:28	3:10	5:1[illegible]

*See Appendix J for airline identifiers.

TABLE A.3 (Continued)

CONSOLIDATION OF TAXI TIMES DCA
(CONTINUED)

	AIRLINE	TYPE AIRCRAFT	36 OUT	36 IN	18 OUT	18 IN	33 OUT	33 IN	15 OUT	15 IN	03 OUT	03 IN	21 OUT	21 IN	OUT	IN	AVG
T	UA	B727	4:01	2:32	3:38	1:33	-	-	-	-	-	-	-	-	3:50	2:02	2:56
M			:39	:03	3:21	:21	-	-	-	-	-	-	-	-	2:00	:12	1:06
Q			-	-	7:30	-	-	-	-	-	-	-	-	-	3:45	-	1:52
Σ			4:40	2:35	14:19	1:54	-	-	-	-	-	-	-	-	9:35	2:14	5:54
T	PI	B727	5:14	2:17	3:19	2:50	-	-	1:40	-	-	-	-	-	3:24	2:14	2:49
M			1:53	:02	3:52	-	-	-	2:20	-	-	-	-	-	2:42	2:34	2:38
Q			:14	-	1:21	-	-	-	8:00	-	-	-	-	-	3:12	:01	1:36
Σ			7:21	2:19	8:32	2:50	-	-	12:00	-	-	-	-	-	9:18	4:49	7:03
T	AVG	B727	4:04	3:18	4:14	2:03	1:58	2:58	2:53	-	3:15	-	-	-	3:17	2:46	3:02
M			1:27	:05	2:18	:06	1:06	-	2:06	-	1:16	-	-	-	1:39	:26	1:02
Q			:07	-	2:55	-	-	-	3:16	-	-	-	-	-	1:16	-	:38
Σ			5:38	3:23	9:27	2:09	3:04	2:58	8:15	-	4:31	-	-	-	6:12	3:12	4:42
T	PI	B737	5:14	2:17	3:19	2:50	-	-	1:40	-	-	-	-	-	3:24	2:34	2:59
M			1:53	:02	3:52	-	-	-	2:20	-	-	-	-	-	2:42	:01	1:22
Q			:14	-	1:21	-	-	-	8:00	-	-	-	-	-	2:52	-	1:26
Σ			7:21	2:19	8:32	2:50	-	-	12:00	-	-	-	-	-	8:58	2:35	5:47
T	UA	B737	3:17	2:01	2:33	2:14	-	2:21	-	-	-	-	-	-	2:55	2:12	2:34
M			2:36	:06	1:47	-	-	-	-	-	-	-	-	-	2:12	:02	1:07
Q			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Σ			5:53	2:06	4:20	2:14	-	2:21	-	-	-	-	-	-	5:07	2:14	3:41
T	AVG	B737	4:16	2:09	2:56	2:32	-	2:21	1:40	-	-	-	-	-	2:57	2:21	2:39
M			2:14	:04	2:49	-	-	-	2:40	-	-	-	-	-	2:28	:01	1:15
Q			:07	-	:40	-	-	-	8:00	-	-	-	-	-	2:56	-	1:28
Σ			6:37	2:13	6:25	2:32	-	2:21	12:00	-	-	-	-	-	8:21	2:22	5:22
T	AL	DC9	2:28	2:38	3:06	2:13	-	-	-	1:54	-	-	-	-	2:47	2:15	2:31
M			:50	-	:24	-	-	-	-	:20	-	-	-	-	:37	:07	:22
Q			:57	-	:26	-	-	-	-	-	-	-	-	-	:42	-	:21
Σ			4:15	2:38	3:56	2:13	-	-	-	2:14	-	-	-	-	4:06	2:22	3:14
T	EA	DC9	3:16	2:59	5:04	1:35	-	-	-	-	-	-	-	-	4:10	2:17	3:14
M			:45	:48	:40	-	-	-	-	-	-	-	-	-	:42	:24	:33
Q			4:55	-	2:22	-	-	-	-	-	-	-	-	-	4:08	-	2:04
Σ			8:56	3:47	9:06	1:35	-	-	-	-	-	-	-	-	9:00	2:41	5:50
T	ML	DC9	2:18	2:45	3:57	-	-	2:25	-	-	-	-	-	-	3:08	2:35	2:52
M			1:31	:06	2:13	-	-	-	-	-	-	-	-	-	1:52	:03	:58
Q			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Σ			3:39	2:51	6:10	-	-	2:25	-	-	-	-	-	-	5:07	2:38	3:50

TABLE A.3

(Continued)

CONSOLIDATION OF TAXI TIMES DCA
(CONTINUED)

AIRLINE	TYPE AIRCRAFT		36 OUT	36 IN	18 OUT	18 IN	33 OUT	33 IN	15 OUT	15 IN	03 OUT	03 IN	21 OUT	21 IN	OUT	IN	AVG
RC	DC9	T	-	-	4:26	1:53	-	-	-	-	-	-	-	-	4:26	1:53	3:10
		M	-	-	1:34	-	-	-	-	-	-	-	-	-	1:34	-	:47
		Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Σ	-	-	6:00	1:53	-	-	-	-	-	-	-	-	6:00	1:53	3:57
OZ	DC9	T	-	-	-	1:50	-	-	-	-	-	-	-	-	-	1:50	1:50
		M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Σ	-	-	-	1:50	-	-	-	-	-	-	-	-	-	1:50	1:50
AVG	DC9	T	2:41	2:47	4:08	1:53	-	2:25	-	1:54	-	-	-	-	3:24	2:15	2:50
		M	1:02	:18	1:13	-	-	-	-	:20	-	-	-	-	1:08	:10	:39
		Q	1:57	-	:57	-	-	-	-	-	-	-	-	-	1:27	-	:44
		Σ	5:40	3:05	6:18	1:53	-	2:25	-	2:14	-	-	-	-	5:59	2:25	4:13
AL	BAC 111	T	-	-	-	1:07	-	3:03	-	-	4:11	-	-	-	4:11	2:05	3:08
		M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Σ	-	-	-	1:07	-	3:03	-	-	4:11	-	-	-	4:11	2:05	3:08
AK	F28	T	2:23	2:09	-	2:43	-	-	-	-	-	-	-	-	2:23	2:26	2:24
		M	2:17	-	-	-	-	-	-	-	-	-	-	-	2:17	-	1:08
		Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Σ	4:30	2:09	-	2:43	-	-	-	-	-	-	-	-	4:30	2:26	3:32
AL	DHC-7	T	-	1:58	-	-	-	-	1:56	1:28	-	-	-	1:34	1:56	1:40	1:48
		M		:14	-	-	-	-	:17	-	-	-	-	-	:17	:05	:11
		Q	-	-	-	-	-	-	:19	-	-	-	-	-	:19	-	:10
		Σ	-	2:12	-	-	-	-	2:32	1:28	-	-	-	1:34	2:32	1:45	2:09
PI	YS-11	T	-	2:07	-	2:44	2:12	1:50	1:42	1:47	-	-	-	3:25	1:57	2:23	2:10
		M	-	-	-	-	:58	-	-	:25	-	-	-	-	:29	:05	:17
		Q	-	-	-	-	-	-	4:59	-	-	-	-	-	2:30	-	1:15
		Σ	-	2:07	-	2:44	3:10	1:50	6:41	2:12	-	-	-	3:25	4:56	2:28	3:42
AK	N262	T	-	-	-	-	-	-	-	4:53	3:20	-	-	-	3:20	4:53	4:06
		M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Σ	-	-	-	-	-	-	-	4:53	3:20	-	-	-	3:20	4:53	4:06
AL	N262	T	-	1:25	-	1:34	3:48	-	-	1:38	3:09	-	-	2:29	3:28	1:47	2:38
		M	-	:15	-	-	:25	-	-	:08	:58	-	-	-	:42	:06	:24
		Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Σ	-	1:40	-	1:34	4:13	-	-	1:46	4:07	-	-	2:29	4:10	1:53	3:02

TABLE A.3

(Continued)

CONSOLIDATION OF TAXI TIMES DCA
(CONTINUED)

	AIRLINE	TYPE AIRCRAFT	36 OUT	36 IN	18 OUT	18 IN	33 OUT	33 IN	15 OUT	15 IN	03 OUT	03 IN	21 OUT	21 IN	OUT	IN	AVG
T	AVG	N262	-	1:25	-	1:34	3:48	-	-	3:16	3:15	-	-	2:29	3:32	2:11	2:52
M			-	:15	-	-	:25	-	-	:04	:29	-	-	-	:27	:05	:16
Q			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Σ			-	1:40	-	1:34	4:13	-	-	3:20	3:44	-	-	2:29	3:59	2:16	3:08
T	AL	SHORT	-	1:24	1:18	2:00	3:40	1:25	1:25	1:51	3:42	1:35	-	2:20	2:31	1:46	2:08
M			-	-	6:27	-	:30	-	:13	-	:29	-	-	-	1:55	-	:58
Q			-	-	-	-	-	-	:34	-	-	-	-	-	:08	-	:04
Σ			-	1:24	7:45	2:00	4:10	1:25	2:11	1:51	4:11	1:35		2:20	4:34	1:46	3:10
T	AL	BE99	5:25	-	-	-	-	-	2:05	-	-	-	-	2:35	3:45	2:35	3:10
M			1:10	-	-	-	-	-	:15	-	-	-	-	-	:42	-	:25
Q			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Σ			6:35	-	-	-	-	-	2:20	-	-	-	-	2:35	4:27	2:35	3:31
T	AK	BE99	-	-	-	-	-	-	3:05	-	-	-	-	2:10	3:05	2:10	2:38
M			-	-	-	-	-	-	2:40	-	-	-	-	-	2:40	-	1:20
Q			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Σ			-	-	-	-	-	-	5:45	-	-	-	-	2:10	5:45	2:10	3:58
T	AVG	BE99	5:25	-	-	-	-	-	2:35	-	-	-	-	2:22	4:00	2:22	3:11
M			1:10	-	-	-	-	-	1:28	-	-	-	-	-	:19	-	:10
Q			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Σ			6:35	-	-	-	-	-	4:03	-	-	-	-	2:22	4:19	2:22	3:21
T	NC		-	-	-	1:41	-	-	-	1:24	-	-	-	-	-	1:32	1:32
M			-	-	-	-	-	-	-	2:47	-	-	-	-	-	1:24	1:24
Q			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Σ			-	-	-	1:41	-	-	-	4:11	-	-	-	-	-	2:56	2:56
T	/L		-	-	-	-	-	-	3:15	2:02	-	-	-	-	3:15	2:02	2:38
M			-	-	-	-	-	-	:30	-	-	-	-	-	:30	-	:15
Q			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Σ			-	-	-	-	-	-	3:45	2:02	-	-	-	-	3:45	2:02	2:53
T	CB		-	-	-	-	4:00	-	2:05	-	-	-	-	-	3:02	-	3:02
M			-	-	-	-	:38	-	-	-	-	-	-	-	:19	-	:19
Q			-	-	-	-	-	-	4:25	-	-	-	-	-	2:12	-	2:12
Σ			-	-	-	-	4:38	-	6:30	-	-	-	-	-	5:33	-	5:33
T	AVG	METRO	-	-	-	1:41	4:00	-	2:40	1:43	-	-	-	-	3:20	1:42	2:31
M			-	-	-	-	:38	-	:15	1:24	-	-	-	-	:26	:42	:34
Q			-	-	-	-	-	-	2:12	-	-	-	-	-	1:06	-	:33
Σ			-	-	-	1:41	4:38	-	5:07	3:07	-	-	-	-	4:52	2:24	3:38

TABLE A.3

(Continued)

CONSOLIDATION OF TAXI TIMES DCA
(CONTINUED)

		36		18		33		15		03		21				
AIRLINE	TYPE AIRCRAFT	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	AVG
T KC	EMBRAER	-	3:20	-	1:58	-	-	2:08	-	-	-	-	-	2:08	2:39	2:24
H		-	-	-	-	-	-	:48	-	-	-	-	-	:48	-	:24
Q		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Σ		-	3:20	-	1:58	-	-	2:56	-	-	-	-	-	2:56	2:39	2:48
T NC	EMBRAER	-	2:00	-	-	-	-	-	-	-	-	-	-	-	2:00	2:00
H		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Q		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Σ		-	2:00	-	-	-	-	-	-	-	-	-	-	-	2:00	2:00
T AVG	EMBRAER	-	2:40	-	1:58	-	-	2:08	-	-	-	-	-	2:08	2:19	2:14
H		-	-	-	-	-	-	:48	-	-	-	-	-	:48	-	:24
Q		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Σ		-	2:40	-	1:58	-	-	2:56	-	-	-	-	-	2:56	2:19	2:38
GA	SE PISTON	-	1:47	-	2:35	5:45	2:58	1:16	4:33	2:56	2:14	2:45	-	3:10	2:49	3:00
GA	ME PISTON	4:40	1:49	-	2:10	8:19	1:30	4:16	7:15	3:19	-	-	-	5:03	3:03	4:03
GA	T PROP	2:40	2:06	-	2:38	5:40	1:40	3:19	3:42	1:44	-	-	-	3:16	2:32	2:54
GA	T JET	2:42	2:12	10:31	2:38	8:40	2:07	3:34	6:18	-	-	-	-	6:17	3:19	4:48

TABLE A.4

CONSOLIDATION OF TAXI TIMES IAD

AIRLINE*	TYPE AIRCRAFT		19R OUT	19R IN	19L OUT	19L IN	01R OUT	01R IN	01L OUT	01L IN	OUT	IN	AVG
AA	B707	T	4:27	1:57	6:41	-	-	-	2:20	4:00	4:28	2:59	3:44
		M	:18	-	3:07	-	-	-	3:50	-	1:53	-	:56
		Q	-	-	-	-	-	-	-	-	-	-	-
		Σ	4:45	1:57	10:48	-	-	-	5:70	4:00	6:21	2:59	4:40
AA	DC10	T	-	3:01	-	3:30	-	-	5:15	2:51	5:15	3:05	4:10
		M	-	-	-	-	-	-	-	-	-	-	-
		Q	-	-	-	-	-	-	-	-	-	-	-
		Σ	-	3:01	-	3:30	-	-	5:15	2:51	5:15	3:05	4:10
NW	DC10	T	-	2:53	4:18	5:42	-	2:30	-	4:11	4:18	3:42	4:00
		M	-	-	:37	-	-	-	-	-	:37	-	:18
		Q	-	-	-	-	-	-	-	-	-	-	-
		Σ	-	2:53	4:55	5:42	-	2:30	-	4:11	4:55	3:42	4:18
UA	DC10	T	9:55	3:56	-	-	-	3:25	5:23	4:42	7:39	4:22	6:00
		M	-	-	-	-	-	-	:28	-	:14	-	:07
		Q	-	-	-	-	-	-	-	-	-	-	-
		Σ	9:55	3:56	-	-	-	3:25	5:51	4:42	7:53	4:22	6:07
AVG	DC10	T	9:55	3:17	4:18	4:36	-	2:58	5:19	3:55	6:31	3:42	5:06
		M	-	-	:37	-	-	-	:14	-	:17	-	:09
		Q	-	-	-	-	-	-	-	-	-	-	-
		Σ	9:55	3:17	4:55	4:36		2:58	5:33	3:55	6:48	3:42	5:15
UA	DC8	T	-	4:05	-	-	-	2:46	-	5:18	-	4:22	4:22
		M	-	-	-	-	-	1:10	-	-	-	:18	:18
		Q	-	-	-	-	-	-	-	-	-	-	-
		Σ	-	4:05	-	-	-	3:56	-	5:18	-	4:40	4:40
BA	B747	T	-	2:03	5:00	4:37	-	4:20	4:39	6:40	4:43	4:25	4:34
		M	-	-	2:40	-	-	-	:38	-	:37	-	:18
		Q	-	-	-	-	-	-	-	-	-	-	-
		Σ		2:03	7:40	4:37	-	4:20	5:17	6:40	5:20	4:25	4:52
PA	B747	T	-	8:09	-	8:35	-	-	-	-	-	8:22	8:22
		M	-	-	-	-	-	-	-	-	-	-	-
		Q	-	-	-	-	-	-	-	-	-	-	-
		Σ	-	8:09	-	8:35	-	-	-	-	-	8:22	8:22
TW	L 1011	T	-	4:27	4:24	-	-	2:18	-	5:16	4:24	4:40	4:34
		M		-	:07	-	-	-	-	:10	:07	:03	:04
		Q	-	-	2:10	-	-	-	-	-	2:10	-	:47
		Σ	-	4:27	6:42	-	-	2:18	-	5:26	6:42	4:43	5:26
AF	Air France Concorde	T	6:10	6:21	-	-	-	-	-	-	6:10	6:21	6:16
		M	:40	-	-	-	-	-	-	-	:40	-	:20
		Q	-	-	-	-	-	-	-	-	-	-	-
		Σ	6:50	6:21	-	-	-	-	-	-	6:50	6:21	6:26

*See Appendix J for airline identifiers.

TABLE A.4

(Continued)

CONSOLIDATION OF TAXI TIMES IAD
(CONTINUED)

			19R		19L		01R		01L				
	AIRLINE	TYPE AIRCRAFT	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	AVG
T	AVG	B747	-	5:06	5:00	6:36	-	4:20	4:39	6:40	4:50	5:41	5:16
M			-		2:40	-	-	-	:38	-	1:39	-	:50
Q			-	-	-	-	-	-	-	-	-	-	-
Σ			-	5:06	7:40	6:36		4:20	5:17	6:40	6:29	5:41	6:06
T	BN	B727	3:50	2:40	-	2:22	-	3:04	2:49	3:37	3:20	2:56	3:08
M			4:03	1:01	-	-	-	-	:25	-	2:14	:15	1:14
Q			-	-	-	-	-	-	-	-	-	-	-
Σ			7:53	3:41	-	2:22	-	3:04	3:14	3:37	5:34	3:11	4:22
T	CO	B727	6:48	2:58	-	3:53	-	3:53	3:22	4:22	5:06	3:46	4:26
M			-	-	-	-	-	-	-	-	-	-	-
Q			-	-	-	-	-	-	1:52	-	:56	-	:28
Σ			6:48	2:58	-	3:53	-	3:53	5:14	4:22	6:01	3:46	4:54
T	UA	B727	-	2:24	5:55	-	-	-	3:55	3:33	4:55	2:58	[illegible]
M			-	-	1:18	-	-	-	-	-	:39	-	:20
Q			-	-	-	-	-	-	-	-	-	-	-
Σ				2:24	7:13	-	-	-	3:55	3:33	5:44	2:58	4:16
T	AVG	B727	5:19	2:40	5:56	3:08	-	3:28	3:22	3:51	4:52	4:12	4:32
M			2:02	:20	1:18	-	-	-	:08	-	1:09	:05	:37
Q			-	-	-	-	-	-	:37	-	:12	-	:06
Σ			7:21	3:00	7:13	3:08	-	3:28	4:07	3:51	6:13	4:17	5:15
T	PC	DC9	-	2:45	2:10	-	-	3:20	3:52	-	3:01	3:02	3:02
M			-	-	-	-	-	-	-	-	-	-	-
Q			-	-	2:07	-	-	-	-	-	1:04	-	:32
Σ				2:45	4:17	-	-	3:20	3:52	-	4:05	3:02	3:34
T	CG	BE 99	1:25	-	5:45	2:17	-	-	-	1:47	3:35	2:02	2:50
M			-	-	-	-	-	-	-	-	-	-	-
Q			8:50	-	-	-	-	-	-	-	4:25	-	2:12
Σ			10:15	-	5:45	2:17	-	-	-	1:47	8:00	2:02	5:02
T	CE	METRO	-	-	2:54	3:32	7:14	2:25	-	2:17	5:04	2:45	3:54
M					:48	-	-	-	-	-	:24	-	:12
Q			-	-	-	-	-	-	-	-	-	-	-
Σ			-	-	3:42	3:32	7:14	2:25		-	5:28	2:45	4:06
	GA	SE PISTON	6:36	-	5:29	2:48	5:37	3:41	-	-	5:37	3:09	4:23
	GA	ME PISTON	5:14	-	4:20	3:46	4:59	3:39	4:42	-	4:47	3:43	4:15
	GA	T PROP	-	-	7:10	3:07	3:22	2:48	-	-	6:27	3:00	4:44
	GA	T JET	-	-	6:58	3:24	5:26	2:39	-	6:07	6:29	3:07	4:48

APPENDIX B

PROCEDURES FOR DISAGGREGATING FAA OPERATIONS DATA BY AIRCRAFT/AIRLINE TYPE

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APPENDIX B

PROCEDURES FOR DISAGGREGATING FAA OPERATIONS DATA BY AIRCRAFT/AIRLINE TYPE

SOURCE OF DATA

FAA statistics on daily operations count at DCA and IAD provided the basic data source for the number of operations at these airports. The FAA publication FAA Air Traffic Activity provided a categorical breakdown of aircraft operations for fiscal year 1979 by air carrier, air taxi, general aviation, aircraft operations (Table B.1). These were then adjusted to calendar year 1979 by use of monthly statistical reports from the Office of Management Systems, Data Systems Division. That is, the data for the last quarter of CY 1979 was substituted for the data for the last quarter of CY 1978. Data for calender year 1979 is shown in Table B.2. Since general aviation operations were not disaggregated in the monthly summaries, FY 1979 percentages were used for this disaggregation. Statistics for the breakdown of aircraft operations on a daily basis were obtained from the FAA Office of Aviation Policy (AVP-120). These breakdowns of categorical operations at each airport were then disaggregated for each selected airport by annual operations, by quarters (seasonal variation), by peak month of the base year, and by the peak day of the base year.

Since the air carrier and air taxi operations statistics obtained from the various sources indicated did not exactly total to the number of

TABLE B.1

FY 1979 AIRCRAFT OPERATIONS AT IAD AND DCA AIRPORTS

AIRPORT/CATEGORY	TOTAL	AIR CARRIER	AIR TAXI	GA	MIL
Dulles Intl.					
Itinerant	131,140	54,814	7,869	65,209	3,248
Local	45,056			39,824	5,232
TOTAL	176,196	54,814	7,869	105,033	8,480
Washington Natl.					
Itinerant	351,460	208,301	47,658	95,091	410
Local	25			9	16
TOTAL	351,485	208,301	47,658	95,100	426

Source: FAA Air Traffic Activity Fiscal Year 1979.

TABLE B.2

CY 1979 AIRCRAFT OPERATIONS AT IAD AND DCA AIRPORTS

AIRPORT/CATEGORY	TOTAL	AIR CARRIER	AIR TAXI	GA	MIL
DULLES INTL					
Itinerant	129258	52484	9143	64149	3482
Local	44786	-	-	39177	5609
Total	174044	52484	9143	103326	9091
WASHINGTON NATL					
Itinerant	352894	207112	48594	96793	395
Local	24	-	-	9	15
Total	352918	207112	48594	96802	410

operations in the FAA Air Traffic Activity operations count, the FAA operations count was used as the base count for aircraft operations and weighted percentages by aircraft type in each operator category at the selected airport used to scale the detailed statistics by aircraft type to the FAA count.

ANNUAL OPERATIONS

In most instances, annual operations data formed the basis for disaggregating operations into number of operations by specific aircraft type. The procedures used for each aircraft category are discussed below:

Aircraft Carrier Operations

Air carrier aircraft operations were disaggregated by airline by summing aircraft operations for Certificated Route Air Carriers, Foreign-Flag Air Carriers, Intra-State Air Carriers and Supplemental Air Carriers. Annual aircraft departures performed by Certificated Route Air Carriers by aircraft type, e.g., B 727-100, B 727-200, DC 8-61, DC 10-10, etc., were obtained from tables of Airport Activity Statistics of Certificated Route Air Carriers, published jointly by the CAB and the FAA.

The number of operations by aircraft type for the Foreign-Flag air carriers was determined by counting the scheduled flights into a particular city by foreign-based carriers from statistics contained in the ICAO publication Traffic Flow and in the Official Airline Guide, International Edition. The number of operations derived from Traffic Flow was based on the assumption that flights to and from the chosen city were made to the selected major airport near that city. The OAG provides statistics on arrivals at specific airports. It was also assumed that for each selected flight, the arrivals were equal to departures to determine total operations. The number of weekly operations in the OAG were counted for a mid-month of the quarter, then multiplied by the number of weeks in the quarter to obtain total operations for the quarter by aircraft type for the Foreign-Flag air carriers at each selected airport during the base year.

The statistics on operations by supplemental air carriers were obtained from the Airport Activity Statistics (AAS) file in the FAA Inquire Data Base. Supplemental air carrier operations were included in the AAS file by carrier. Weighted percentages of the operator's fleet mix were used to make estimates of operations by aircraft type. The fleet mix for supplemental carriers was contained in Schedule T6, Form 41 from the Civil Aeronautics Board.

Dulles International Airport (IAD). Table B.3 presents the 1979 scheduled and non-scheduled departures from IAD by Air Carrier (domestic and international) by aircraft type. To these are added the Foreign-Flag Carriers (Table B.4). This gives a total of 51,826 air carrier operations versus the 52,484 operations reported by the FAA. The values shown for the U.S. carriers were then scaled to achieve the FAA figures. The difference between the FAA tower operations and those identified by ORI may be due to unscheduled operations.

Washington National Airport (DCA). An examination of the Foreign-Flag carriers servicing Washington, D.C., revealed they were all of a type aircraft (B-747, IL-62) which did not operate out of DCA. Therefore, all Foreign-Flag carrier operations were allocated to IAD. Table B.5 lists the air carrier departures for DCA. Doubling these values (since it was assumed that for every departure there was an arrival) gives a value of 204,844 operations versus the 207,112 reported by the FAA. The aircraft types were then scaled to obtain the FAA data.

Air Taxi Operations

The number of operations by aircraft type for scheduled Air Taxi Operators was obtained from statistics contained in the Official Airline Guide, North American Edition. The number of scheduled arrivals per week was summed by aircraft type for a week in the mid-month of each quarter and multiplied by the number of weeks in the quarter. It was assumed that the number of departures was equal to the number of arrivals to obtain total operations.

TABLE B.3

1979 SCHEDULED AND NON-SCHEDULED DEPARTURES FROM IAD
BY AIRCRAFT TYPE AND CARRIER (DOMESTIC AND INTERNATIONAL FLIGHTS)
CERTIFICATED CARRIERS ONLY

Aircraft Type	# of Flights by Carrier: American Airlines	Altair Airlines	Braniff Airways	Continental Airlines	Delta Airlines	Eastern Airlines	Northwest Airlines	Ozark Airlines	Pan American	Piedmont Aviation	Republic Airlines	Seaboard World Air.	Southern Airways*	Transworld Airlines	United Airlines	Western Airlines	TOTAL
B 727 100	237	–	237	299	–	921	2	–	–	3	–	–	–	8	353		2060
*B 727 100 C/QC	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	2
B 727 100 C/QC		–	889	–	–	511	–	–	–	–	–	–	–	1	–	–	1401
B 727 200	483	–	2135	976	270	350	14	–	–	–	–	–	–	121	21	1	4370
B 707 100B	1262	–	–	–	–	–	–	–	–	–	–	–	–	1019	–	–	2281
B 707 300	–	–	–	–	–	–	–	–	–	–	–	–	–	46	–	–	46
B 707 300B	465	–	–	–	–	–	–	–	626	–	–	–	–	1161	–	–	2251
B 707 300C	581	–	–	–	–	–	–	–	–	–	–	–	–	123	–	–	704
B 737 200	–	–	–	–	–	–	–	–	–	27	–	–	–	–	310	–	337
B 747	1	–	–	–	–	–	348	–	663	–	–	–	–	4	2	–	1018
*B 747 F	–	–	–	–	–	–	1	–	–	–	–	1	–	–	–	–	2
B 747 SP	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	2
DC 8 50	–	–	21	–	6	–	–	–	–	–	–	–	–	–	1066	–	1093
*DC 8 50F	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1
DC 8 61	–	–	–	–	–	–	–	–	–	–	–	–	–	–	963	–	963
DC 8 62	–	–	283	–	–	–	–	–	–	–	–	–	–	–	437	–	720
DC 9 10	–	–	–	–	–	–	–	224	–	–	904	–	987	2	–	–	2117
DC 9 30	–	–	–	–	263	365	–	738	–	–	69	–	57	–	–	–	1492
DC 9 50	–	–	–	–	–	6	–	–	–	–	–	–	–	–	–	–	6
DC 10 10	619	–	–	–	–	–	–	–	–	–	–	–	–	–	787	–	1406
DC 10 40	–	–	–	–	–	–	598	–	–	–	–	–	–	–	–	–	598
L 1011	–	–	–	–	1	1	–	–	–	–	–	–	–	674	–	–	676
N 262	–	1214	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1214
YS 11	–	–	–	–	–	–	–	–	–	142	–	–	–	–	–	–	142
SSC Concorde	–	–	231	–	–	–	–	–	–	–	–	–	–	–	–	–	231
TOTAL	3648	1214	3758	1274	540	2154	963	962	1290	172	973	1	1044	3159	3940	1	25 133

*Combined with Southern Airways to form Republic Airlines.

SOURCE: FAA Airport Activity Statistics, 1979, pp. 185-186.

TABLE B.4

DIRECT ARRIVALS TO WASHINGTON, D.C. BY QUARTER 1979

	British Airways					Air France					Aeroflot					
Aircraft Type	Mid Feb	Mid May	Mid Aug	Mid Nov	Total	Mid Feb	Mid May	Mid Aug	Mid Nov	Total	Mid Feb	Mid May	Mid Aug	Mid Nov	Total	Grand Total
B747	78	91	91	91	351											351
VC10	13				13											13
SSC	39	39	39	39	156	52	52	52	52	208						364
IL 62											13	13	13	13	52	52
	130	130	130	130	520	52	52	52	52	208	13	13	13	13	52	780

SOURCE: Official Airline Guide, International Edition, February, May, August and November 1979.

TABLE B.5

1979 SCHEDULED AND NON-SCHEDULED DEPARTURES FROM DCA
BY AIRCRAFT TYPE AND CARRIER (DOMESTIC AND INTERNATIONAL FLIGHTS)
CERTIFICATED CARRIERS ONLY

Aircraft Type	# of Flights by Carrier																	TOTAL
	American Airlines	Altair Airlines	U.S. Air	Braniff Airways	Delta Airlines	Eastern Airlines	National Airlines	New Haven Airways	N. Central Airlines*	Northwest Airlines	Piedmont Aviation	Air Florida	Republic Airlines	Transworld Airlines	United Airlines	Empire Airlines	Western Airlines	
B 727 100	2763	–	340	139	–	2960	2378	–	–	1099	1336	–	–	1790	1087	–	–	13 881
B 727 200	6614	–	–	3138	6770	7426	2918	–	–	5334	–	–	–	4453	3520	–	337	39 516
BH 99	–	347	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	347
N 262	–	1010	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1010
MO 298	–	–	342	–	–	–	–	–	–	–	–	–	–	–	–	–	–	342
BAC 111 200	–	–	4559	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4559
DC 9 30	–	–	7616	–	241	13,758	–	–	–	–	–	–	53	–	–	–	–	21 568
B 727 100 C/QC	–	–	–	742	–	1531	–	–	–	–	–	–	–	645	–	–	–	2918
DC 9 10	–	–	–	–	–	57	–	–	–	–	–	182	1	1	–	–	–	241
DC 9 50	–	–	–	–	–	3533	–	–	12	–	–	–	289	–	–	–	–	3834
PA 31/34/39	–	–	–	–	–	–	–	253	–	–	–	–	–	–	–	9	–	262
PA 23 250	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	1
Embraer	–	–	–	–	–	–	–	81	–	–	–	–	–	–	–	–	–	81
YS 11	–	–	–	–	–	–	–	–	–	–	5617	–	–	–	–	–	–	5517
B 737 200	–	–	–	–	–	–	–	–	–	–	6233	364	–	–	4131	–	–	9728
Swear Metro	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	118	–	118
TOTAL	9377	1357	12,857	4019	6011	29,254	5293	335	12	6,433	12,085	546	343	6789	8747	127	337	103,922

*Combined with Southern Airways to form Republic Airlines.

SOURCE: FAA Airport Activity Statistics, 1979, pp. 185-186.

Dulles International Airport (IAD). A breakout of air taxi/commuter airline arrivals at IAD is shown in Table B.6. Assuming a departure for each arrival would give 8,502 air taxi operations at IAD for 1979. This differs from the FAA tower count of air taxi operations for FY 1979 of 9,143. Air taxi operations were then scaled to agree with the FAA figures.

Washington National Airport (DCA). The breakout of air taxi operations at DCA are shown in Table B.7. Here once again the scheduled operations (42,216) are scaled up to agree with the reported FAA count (48,594).

General Aviation Aircraft Operations

No specific count is made by FAA tower operations pertaining to general aviation operations except whether the traffic is local or itinerant. Two procedures were used to gain some insight into the disaggregation of general aviation traffic mix: (1) disaggregation based upon the ratio of general aviation aircraft registered in the county in which the airport is located and (2) use of airport survey data which was the basis for determining the general aviation aircraft traffic mix in the Aircraft Environmental Data Base (AEDB) in the FAA Inquire Data Base. A combination of these procedures - use of the county registration breakout for local operations and use of the AEDB actual survey information for itinerant operations were used to provide the most representative mix by type of aircraft for general aviation operations.

Data used for the county breakout was obtained from the Census of Aircraft 1979 for Arlington County, Virginia (for DCA) and Loudon County, Virginia (for IAD). The percentages for these aircraft are shown in Table B.8 for each airport of interest.

For itinerant general aviation operations, the percentage by aircraft categories were derived by accumulating data from the following sources: AEDB survey data; EPA Technical Report AC 77-01, Aircraft Emissions at Selected Airports, 1972-1975, January 1977; flight strips at DCA for a complete week in addition to a peak traffic day and an exceptionally light traffic day; and

TABLE B.6

1979 DIRECT NON-CERTIFICATED COMMUTER ARRIVALS TO IAD BY AIRCRAFT TYPE AND CARRIER

AIRCRAFT TYPE	CALGAN AIRLINES					CARDINAL/AIR VIRGINIA					ALTAIR AIRLINES					GRAND TOTAL
	FEB. 15	MAY 15	AUG. 15	NOV. 15	TOTAL	FEB 15	MAY 15	AUG. 15	NOV. 15	TOTAL	FEB. 15	MAY 15	AUG. 15	NOV. 15	TOTAL	
BE-99	559	702	702	754	2,717											2,717
Piper Navaho							13	91	403	507						507
Piper Chieftain							143	221	221	585						585
NORD 262												208	234		442	442
TOTAL	559	702	702	754	2,717	0	156	316	624	1,092	0	208	234	0	442	4,251

Source: Official Airline Guide, North American Edition, February 15, May 15, August 15, and November 15, 1979.

TABLE B.7

1979 NON-CERTIFICATED AND COMMUTER DIRECT ARRIVALS TO DCA BY AIRCRAFT TYPE AND CARRIER

	ARRIVALS BY CARRIER							
AIRCRAFT TYPE	ALTAIR	ALLEGHENY	COMMUTER	CUMBERLAND	MONMOUTH	NEW HAVEN	OCEAN	TOTAL
BE-99	325	3,016		312	416		442	4,511
CV-580			624					624
DH-6		1,300						1,300
Bandierante						65		65
N-262	78	7,052						7,130
PA-31			585	468				1,053
CS-330		5,424						5,424
SW-4			403					403
TS-60					130			130
DH-7		468						468
TOTAL	403	17,260	1,612	780	546	65	442	21,108

Source: Official Airline Guides, February 15, May 15, August 15 and November 15, 1979.

TABLE B.8

PERCENTAGE BREAKOUT OF LOCAL GENERAL AVIATION
AIRCRAFT AT DCA AND IAD AIRPORTS

AIRCRAFT CATEGORY	AIRPORT	
	DCA	IAD
Single Engine Piston	24.5	91.1
Multi-Engine Piston	38.7	8.0
Turboprop	20.4	-
Turbojet	8.2	-
Rotorcraft	8.2	0.9
TOTAL	100.0	100.0

conversations with the airport managers. The percentage distribution of general aviation itinerant operations at DCA and IAD are shown in Table B.9 It is noted there are no rotorcraft itinerant aircraft listed.

Because of the exceptionally large number of general aviation type aircraft, each category (single engine piston, multi-engine piston, turbojet, turboprop and helicopter) were disaggregated by engine size and a representative aircraft selected for each grouping. Percentages were then determined based upon the number of aircraft of that type registered in the U.S. as reported in the Census of Aircraft 1979. This breakout is shown in Table B.10.

Military Aircraft Operations

Since military operations make up such an insignificant number of operations at DCA (less than 0.1%) and IAD (less than 5%) they were not included in this study effort.

SEASONAL (QUARTERLY) OPERATIONS

Air Carrier

Since the 1979 Tower Airport Statistics Handbook had not been published at the time the operations data was disaggregated, seasonal variation of air carrier operations in 1979 were obtained by assuming the variation in operations would be the same as they were in 1978. From the Tower Airport Statistics Handbook, April 1979, it was determined that the percentage variation of air carrier operations for 1978 were as shown in Table B.11. Multiplying these percentages by the total air carrier operations at each airport of interest gave the seasonal variation for 1979.

Air Taxi

Air taxi operations were determined based upon determining the number of arrivals during a week in the middle of each quarter, multiplying by the number of weeks in that quarter and then summing to obtain total operations. Scaling was then performed to arrive at the FAA tower count.

TABLE B.9

PERCENTAGE BREAKOUT OF ITINERANT GENERAL
AVIATION AIRCRAFT AT DCA AND IAD AIRPORTS

AIRCRAFT CATEGORY	AIRPORT	
	DCA	IAD
Single Engine Piston	21.4	60.0
Multi-Engine Piston	35.3	27.0
Turboprop	13.2	4.0
Turbojet	30.1	9.0
TOTAL	100.0	100.0

TABLE B.10

PERCENTAGE BREAKOUT OF GENERAL AVIATION
BY AIRCRAFT CATEGORY

SINGLE ENGINE PISTON		MULTI-ENGINE PISTON		TURBOJET	
AIRCRAFT TYPE	%	AIRCRAFT TYPE	%	AIRCRAFT TYPE	%
C-150	40.0	PA-30	9.0	Falcon 20	37.3
PA-28	13.0	Pase	6.0	LJ 35	34.5
C-172	13.0	C-337	7.0	C 500	28.2
C-177	9.0	BE-50	3.0		--
C-182	19.0	C-310	56.0	TOTAL	100.0
C-210	6.0	C-401	14.0		
	--	BE-65	5.0		
TOTAL	100.0		--		
		TOTAL	100.0		

TURBOPROP		ROTORCRAFT	
AIRCRAFT TYPE	%	AIRCRAFT TYPE	%
BE-65-90	56.0	47G2	50.0
MU-2B	44.0	206B1	50.0
TOTAL	100.0	TOTAL	100.0

TABLE B.11

SEASONAL (QUARTERLY) PERCENTAGES FOR IAD AND DCA AIRPORTS
BY TYPE OF CARRIER, 1979

QUARTER	AIR CARRIER		AIR TAXI		GENERAL AVIATION	
	IAD	DCA	IAD	DCA	IAD	DCA
January - March	24.8	24.5	13.1	25.1	21.1	21.5
April - June	25.6	25.0	25.1	24.3	27.9	27.8
July - September	25.4	24.8	29.4	26.1	28.5	25.9
October - December	24.2	25.7	32.4	24.5	22.5	26.8
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0

Seasonal variation was determined using the quarterly percentages multiplied by the total operations. These percentages for IAD and DCA are shown in Table B.11.

General Aviation

The procedure used to obtain the seasonal (quarterly) operations for general aviation was determined in the same manner as for air carrier aircraft. The percentages used are shown in Table B.11.

PEAK MONTH OPERATIONS

Peak month operations were determined by obtaining the peak month figures from the airport tower manager and assuming the disaggregation would be the same as that which occurred in 1978. The peak month for DCA (October) and IAD (September) are shown in Table B.12.

PEAK DAY OPERATIONS

Peak day operations were determined using a similar procedure to that used for peak month operations. These disaggregated values are shown in Table B.13.

TABLE B.12

PEAK MONTH OPERATIONS

AIRPORT/CATEGORY	TOTAL	AIR CARRIER	AIR TAXI	GA
IAD				
Itinerant	11628	4705	410	6223
Local	4268	-	-	3800
Total	15896	4705	410	10023
DCA				
Itinerant	32633	18640	4471	9487
Local	2	-	-	1
Total	32635	18640	4471	9488

TABLE B.13

PEAK DAY OPERATIONS

AIRPORT/CATEGORY	TOTAL	AIR CARRIER	AIR TAXI	GA
IAD				
Itinerant	829	481	17	321
Local	211	-	-	196
Total	1040	481	17	517
DCA				
Itinerant	1239	654	123	436
Local	-	-	-	-
Total	1239	654	123	436

APPENDIX C

FUEL BURN RATES

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APPENDIX C

FUEL BURN RATES

The methodology used by ORI for determining the fuel consumption rates for aircraft in current use at Dulles International and Washington National airports consisted of the following steps:

1. Aircraft operations data, described in Appendix B identified those aircraft, by type and airline, with operations at IAD and DCA.

2. Based upon the airline and aircraft type identified in 1 above, the applicable engine designation was determined.

3. For each engine type identified in 2 above, the fuel flow rate at idle was determined.

4. If information on a particular model of an engine series was not available, fuel flow rates for an engine in the series which most nearly matched the missing engines takeoff thrust rating was used.

ENGINE IDENTIFICATION

As discussed in Appendix B, aircraft operations at IAD and DCA were determined for the three categories: air carrier, air taxi, and general aviation. A breakdown by aircraft type was then developed within each of the categories as shown in Tables B.3 through B.7 and B.10.

Matrixes similar to the aircraft operations tables (except engine designations replaced the numbers of operations) were then developed for the air carrier and air taxi aircraft (Tables C.1 and C.2) from information contained in the "Turbine-Engined Fleets of the World's Airlines 1979" Supplement to Volume 21, No. 3, 1979 Air World Survey. Since many of the commuter airlines were not included in this data source, fleet mix data was verified in the 1980 Commuter Airline Industry Annual Report.

Following deregulation, the airline industry became very fluid and as such many differences were found to exist between the operational data published in the FAA/CAB Air Traffic 1979, Official Airline Guides (U.S.) and International Editions) and other source data. For example, airline schedules reflected operations with aircraft not included in the airlines inventory. This was especially true for the mix of B 727-100, B 727-100C/QC, and B 727-200 aircraft. In addition, it was noted that airlines either changed their names, e.g., (New Haven is now designated New Air and Alleghany is now US Air) or merged (e.g., Southern and North Central Airlines have merged into Republic Airlines). Data was used for those airlines and aircraft that were operating in 1979. If no data was observed, the average taxi time for the particular aircraft of interest was utilized.

Using the list of engines, fuel flow rates for each engine were determined. It is noted that a large amount of data (with much of it out of date) has been published and is available today in government and industry reports. This data generally presents fuel flow rates at various power settings as a percentage of F_{00}, where F_{00} is the take-off thrust rating developed under ISA sea level static conditions and under the maximum conditions of rotational speed and exhaust gas temperature approved for use in normal take off without the use of water injection. Power settings most commonly reported are take-off (100% F_{00}), climb-out (85% F_{00}), approach (30% F_{00}), and idle. The percent of thrust at idle varies by engine type and is generally reported as either actual idle for that engine or at 7% F_{00} in response to the proposed ICAO standards on aircraft engine emissions.

TABLE C.1

ENGINE DESIGNATION BY AIRLINE AND AIRCRAFT TYPE IAD

	American Airlines	Altair Airlines	Braniff Airways	Continental Airlines	Delta Airlines	Eastern Airlines	Northwest Airlines	Ozark Airlines	Pan American	Piedmont Aviation	Republic Airlines	Seaboard World Air.	Transworld Airlines	United Airlines	Western Airlines	British Airways	Air France	Aeroflot •
B727 100			JT-8D 7A	JT-8D 7/9			JT-8D 7A											
B727 100 C/QC			JT-8D 1/7A															
B727 100 C/QC	JT-8D 9		JT-8D 1/7A															
B727 200	JT-8D 9		JT-8D 9	JT-8D 9	JT-8D 15	JT-8D 7B 15	JT-8D 7A						JT-8D 15	JT-8D 7A/B	JT-8D 9/15			
B707 100B	JT 3D 3												JT 3D 3B					
B707 300																		
B707 300B	JT-3D 3								JT 3D 3B				JT 3D 3B					
B707 300C	JT-3D 3												JT-3D 3B					
B737 200										JT 8D 7/9				JT-8D 7A/B				
B747	JT 9D 3A						JT-9D 7		JT 9D 7A				JT-9D 3A			JT-9D 3A		
B747F							JT-9D 7F					JT-9D 70		JT-9D 3				
B747SP									JT 9D 7A									
DC8 50			JT-3D 7		JT-3D 1									JT-3D 3B				
DC8 50F														JT 3D 3B				
DC8 61														JT 3D 3B				
DC8 62			JT 3D 3B											JT 3D 7				
DC9 10								JT 8D 7			JT 8D 7		JT 8D 5					
DC9 30					JT 8D 7A	JT-8D 7B		JT 8D 7			JT 8D 7/9/15							
DC9 50						JT-8D 17												
DC10 10	CF6 6D													CF6 6D				
DC10 40							JT 9D 20											
L1011					RB 211 22B	RB 211							RB 211 22B					
N262		Bastan VIC																
YS11										Dart 542 10B								
SSC Concorde			SNECMA Olympus 593													Olympus 593	Olympus 593	
VC10																Conway 550B		
IL62																		NK 8 4

Source: FAA Airport Activity Statistics
Supplement to Volume 31 No 3 1979 Air World Survey
Turbine Engine Fleets of the World's Airlines 1979
1980 Annual Report Commuter Airline Industry

TABLE C.2

ENGINE DESIGNATION BY AIRLINE AND AIRCRAFT TYPE DCA

	American Airlines	Altair Airlines	U.S. Air	Braniff Airways	Delta Airlines	Eastern Airlines	National Airlines	New Haven Airways*	Northwest Airlines	Piedmont Aviation	Air Florida	Republic Airlines**	Transworld Airlines	United Airlines	Empire Airlines	Western Airlines
B727-100			JT-8D-7						JT-8D-7A	JT-8D-7						
B727-100 C/QC																
B727-200	JT-8D-9		JT-8D-17	JT-8D-9/17A	JT-8D-15	JT-8D-7B-15	JT-8D-7		JT-8D-7A				JT-8D-15	JT-8D-7A, B		JT-8D-9-15
B737-200											JT-8D-7	JT-8D-7/9		JT-8D-7A/B		
DC9-10						JT-8D-7B						JT-8D-7	JT-8D-5			
DC9-30			JT-8D-7/9		JT-8D-7A	JT-8D-7B										
DC9-50						JT-8D-17						JT-8D-17				
N262		Bastan VIC														
YS11												Dart 542-10J				
BH-99		PT-6A-20														
MO298																
BAC111-200			SPE-Y506 14DW													
PA Navaho																
PA Chieftain																
Embraer																
Swear Metro															TPE 331-303	

*Name changed to New Air

**Formed by the merger of North Central and Southern Airlines

Source: FAA Airport Activity Statistics
Supplement to Volume 31 No. 3 1979 Air World Survey Turbine Engined Fleets of the World's Airlines 1979
1980 Annual Report Commuter Airline Industry

The primary source of data for determining fuel flow rates was the work previously completed by ORI as part of the FAA report Impact of Applying Alternate Aircraft Engine Emission Standards on Air Quality (FAA Report No. FAA-EE-79-14). This information was supplemented with material provided by the aircraft engine manufacturers (especially GE, P&WA and RR). As part of this effort, the major U.S. engine manufacturers were requested to revalidate the engine emissions data base and to provide, if available, fuel flow curves in the vicinity of engine idle. The Rolls Royce data was updated by ORI based upon data submitted to FAA-EE entitled The Variability of Production RB 211-524B-02 Engine Exhaust Emissions.

Table C.3 lists the fuel flow rates for selected aircraft engines installed in aircraft which operate within the United States. The engines are listed in order of application - air carrier, air taxi, and general aviation. Fuel flow rates are shown for the engine manufacturer's idle, ICAO idle (7% F_{oo}), approach (30% F_{oo}), climbout (85% F_{oo}) and take-off (100% F_{oo}). Fuel flow rates for the entire landing/take-off (LTO) cycle were included in the event, at a later date, FAA desired to compute the fuel consumed during the entire LTO sequence rather than just during the ground operations portion.

As mentioned above, it was recognized that there are a number of government and industry reports available today that present fuel flow rates. Industry's concern with fuel economy and engine emissions has produced more accurate data measured by the manufacturers under stringent conditions. The results of these measurements are reflected in the table.

For example, the data for the JT-8D, JT-9D and CF-6 series of engines has been coordinated with the manufacturers (P&WA and GE). The remainder of the air carrier engines plus those used in commuter aircraft were extracted from the engine data submitted for the ICAO aircraft engine emission data base. ORI participated in the collection of this data and considers it to be up-to-date. This conclusion is based upon agreement between the fuel flow rates received from the manufacturers and the ICAO data for similar power settings on the same engines. The EPA Notice of Proposed Rule Making (NPRM) on Control of Air Pollution from Aircraft and Aircraft

TABLE C.3

FUEL FLOW RATES

			M_f (Kg/Hr)			
ENGINE	IDLE (% F_{oo})	7% F_{oo}	30% F_{oo}	85% F_{oo}	100% F_{oo}	SOURCE
JT 3D 7	408 (4.7)	NA	1334	3629	4468	P&WA
JT 8D 9	461 (6.0)	475	1072	3044	744	P&WA
JT 8D 17	519 (6.4)	529	1275	3588	4481	P&WA
JT 9D 7	760 (6.4)	790	2109	6078	7303	P&WA
JT 9D 70	744 (5.6)	853	2449	7199	8791	P&WA
CF 6 60	466 (3.0)	677	1728	5207	6304	GE
CF 6 50C	549 (3.3)	764	2392	7032	8552	GE
CFM 56*	402 (6.0)	410	1010	2815	3380	GE
RB211-22B	627 (4.6)	791.28	2001.6	5540.4	6706.8	RR
TFE 731-2-2B	NA	86.4	241.2	622.8	738	AiResearch
TFE 731-3	NA	93.6	259.2	669.6	810	AiResearch
CF 6-32*	NA	626.4	1555.2	4701.6	5734.8	GE (based on CF 6-6 corrected to CF 6-32 cycles)
CF 6-45	NA	727.2	2178	6372	7653.6	GE (based on CF 6-50 corrected to CF 6-45 cycles)
CF 34	173 (6.4)	193.68	432	1177.2	1418.4	GE (based on TF 34 corrected to CF 34 cycles)
JT 8D-209	NA	544.32	1265.4	3510.72	4354.56	P&WA
JT 9D-7F (MOD V)	NA	788.4	2245.32	6350.4	7801.92	P&WA
JT 15D	NA	82.8	183.6	446.4	532.8	P&WA
JT 15D-4	NA	77.76	212.4	514.8	610.92	P&WA
M 45H-01	NA	190.8	525.6	1497.6	1792.8	RR
RB 211-524B2	661 (NA)	979.2	2494.8	6980.4	8578.8	RR
RB 211-535	544 (NA)	662.4	1944	5328	6573.6	RR
SPEY M 511	401 (NA)	428.4	1004.4	2613.6	3200.4	RR
SPEY MK 555	341 (NA)	414	799.2	2120.4	2592	RR
OLYMPUS 593 M610	NA	2466(15%) 1515.6	4215.6 (34%)	8384.4 (65%)	22914	RR
ALF 502D	168 (6.2)	NA	354	1005	1205	EPA (Pace Report)
ALF 502L	173 (5.3)	NA	478	1185	1416	EPA (Pace Report)
CJ 610-2C	231.3 (NA)	NA	464.9	1102.0	1261.0	EPA (Pace Report)
PB 401-06	149.7 (NA)	NA	351.5	966.2	1089	EPA (Pace Report)
TPE 331-2	47.6 (NA)	NA	99.8	168.7	183.7	EPA (Pace Report)
PT 6-27	52.16 (NA)	NA	97.52	181.4	192.8	EPA (Pace Report)
250 B 17B	28.58 (NA)	NA	38.56	111.1	120.2	EPA (Pace Report)
501 D 22A	276.7 (NA)	NA	517.1	997	1078	EPA (Pace Report)
DART R DA 7	186.4 (NA)	NA	292.6	566.1	639.1	EPA (Pace Report)
PR TYNE	280.8 (NA)	NA	496.7	992.5	1076	EPA (Pace Report)
IO 520F	13.6 (NA)	NA	38.1	67.1	90.7	EPA (Pace Report)
T SIO-520E	11.8 (NA)	NA	40.8	77.1	97.1	EPA (Pace Report)
IO-540E	11.8 (NA)	NA	24.5	58.1	78.9	EPA (Pace Report)
T SIO-360E	18.1 (NA)	NA	54.4	107	136.1	EPA (Pace Report)
0470 U	10.9 (NA)	NA	29.5	54.4	68	EPA (Pace Report)
JT 3C	543 (NA)	NA	1867	3860	4619	EPA AP 42
JT 4A	630 (NA)	NA	2719	5927	7036	EPA AP 42
CJ 805	454 (NA)	NA	1713	3760	4518	EPA AP 42
T 56-A15	224 (NA)	NA	520	992	1085	EPA AP 42
T 56-A7	249 (NA)	NA	478	865	943	EPA AP 42
O-200	3.48 (NA)	NA	9.66	22	22	EPA AP 42
O-320	5.9 (NA)	NA	10.5	28.8	29.8	EPA AP 42

*Current Development Status

Engines, dated March 24, 1978, did not recommend standards for general aviation type aircraft. Therefore, up-to-date data on emission and fuel flow rates have not been published recently for general aviation aircraft. ORI used information appearing in two earlier EPA reports - EPA Technical Support Report, Aircraft Emission Factors, March 1977, by Robert A. Pace, and EPA, Compilation of Air Pollutant Emission Factors, Report AP 42 Part A. Both of these reports were considered the basic source of engine data a few years ago. In addition, the current file of EPA data, as yet unpublished, has been evaluated.

During the conduct of the various fuel conservation procedures, it was noted that the assumption that the aircraft could taxi at idle power was not appropriate under certain scenarios. In these instances, ORI computed the thrust required from fuel flow curves prepared by ORI.

APPENDIX D

AIRLINE OPERATING PRACTICES

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APPENDIX D

AIRLINE OPERATING PRACTICES

GENERAL

Airline personnel at Washington National and Dulles International Airports were interviewed to develop a general perspective concerning operating practices being used to conserve fuel. All of the airlines were found to be devoting significant attention to conservation of fuel during ground operations as well as in the air. Significant differences in operating practices were mainly associated with equipment availability and characteristics. B 737 pilots, for example, rarely taxi in or out on one engine because thrust from a single operating engine produces undesirable steering forces. Pilots operating another two engine aircraft, the DC 9, do taxi on a single engine because DC 9 engines are located much nearer the aircraft center line and single engine thrust does not produce undesirable steering forces. Tables D.1 through D.3 summarize the airline operating procedures at DCA and IAD airports. Details on each airline are presented below. Reports of the ORI interviews are shown as an annex to this appendix.

TABLE D.1

AIRLINE OPERATING PRACTICES DCA NORTH OPERATIONS

AIRPORT-WASHINGTON NATIONAL NORTH OPERATION	AMERICAN	BRANIFF	DELTA	EASTERN	NORTHWEST	PAN AM	PIEDMONT	UNITED	U.S. AIR	TRANS WORLD
GATE OPERATION										
1. Use APU (with time and/or climate controls)	X	X	X	X	X	X	X	X	X	X
2. Use GPU		X	X		X	X		X		X
GATE DEPARTURE										
1. Hold at gate when delays long	X	X	X	X	X	X	X	X	X	X
2. Establish position in departure line	X	X	X	X	X	X	X	X	X	X
3. Start APU if not operating						X		X		X
4. Start engines at gate	No	No	No	No	No	No	No	No	No	No
5. Start engines during push-back		X		X	X	X		X	X	X
6. Start engines after push-back disconnect	X		X				X	X		
TAXI FOR TAKE-OFF										
1. Use all engines*	90%	90%	90%	75%	90%	90%	90%	90%	90%	90%
2. Use less than all engines	10%	10%	10%	25%	10%	10%	10%	10%	10%	10%
3. Shut down APU for taxi								X	X	
4. Shut down APU prior to take-off	X	X	X	X	X	X				X
5. Shut down APU when airborne							X			
DELAYS DURING DEPARTURE TAXI										
1. Taxi with less than all engines	X	X	X	X	X	X	X	X	X	X
2. Shut down APU for long delays	X		X	X			X	X	X	X
ARRIVAL OPERATIONS										
1. Use optimum runway exit	X	X	X	X	X	X	X	X	X	X
2. Use all engines*					50%	B-737	B-737	B-737		
3. Use less than all engines	X	X	X	X	50%	X	X	X	X	X
4. Start APU for gate arrival	X	X	X	X	X	X	X	X	X	X
MAINTENANCE AND OVERNIGHT										
1. Use APU	X				X		X			
2. Use GPU	X	X	X	X		X		X	X	X
3. Tow aircraft to and from gate	X	X	X	X	X	X	X	X	X	X
4. Taxi aircraft except for push-back	No	No	No	No	No	No	No	No	No	No

*B-737's, YS-11's and BE-99 aircraft taxi out and in with all engines operating.

X = Actual Procedure Used
No = Procedure Not Used

TABLE D.2

AIRLINE OPERATING PRACTICES-DCA SOUTH OPERATIONS

AIRPORT-WASHINGTON NATIONAL SOUTH OPERATION	AMERICAN	BRANIFF	DELTA	EASTERN	NORTHWEST	PAN AM	PIEDMONT	UNITED	U.S. AIR	TRANS WORLD
GATE OPERATION										
1. Use APU (with Time Controls)	X	X	X	X	X	X	X	X	X	X
2. Use GPU		X	X		X	X		X		X
GATE DEPARTURE										
1. Hold at gate when delays long	X	X	X	X	X	X	X	X	X	X
2. Establish position in departure line	X	X	X	X	X	X	X	X	X	X
3. Start APU if not operating						X		X		X
4. Start engines at gate	No	No	No	No	No	No	No	No	No	No
5. Start engines during push-back	No	X	No	X	X	X	_	X	X	X
6. Start engines after disconnect	X		X				X	X		
TAXI FOR TAKE-OFF										
1. Use all engines*	90%	90%	90%	75%	90%	90%	90%	90%	90%	90%
2. Use less than all engines	10%	10%	10%	25%	10%	10%	10%	10%	10%	10%
3. Shut down APU for taxi								X	X	
4. Shut down APU prior to take-off	X	X	X	X	X	X		X		X
5. Shut down APU when airborne							X			
DELAYS DURING DEPARTURE TAXI										
1. Taxi with less than all engines	X	X	X	X	X	X	X	X	X	X
2. Shut down APU for long delays	X		X	X			X	X	X	X
ARRIVAL OPERATIONS										
1. Use optimum runway exit	X	X	X	X	X	X	X	X	X	X
2. Use all engines*					50%	B-737	B-737	B-737		
3. Use less than all engines	X	X	X	X	50%	X	X	X	X	X
4. Start APU for gate arrival	X	X	X	X	X	X	X	X	X	
MAINTENANCE AND OVERNIGHT										
1. Use APU	X				X		X			
2. Use GPU	X	X	X	X		X		X	X	X
3. Tow aircraft to and from gate	X	X	X	X	X	X	X	X	X	X
4. Taxi aircraft except for push-back	No	No	No	No	No	No	No	No	No	No

*B-737's, YS-11's and BE-99 aircraft taxi out and in with all engines operating.

X = Actual Procedure Used
No = Procedure Not Used

TABLE D.3

AIRLINE OPERATING PRACTICES-IAD

AIRPORT-DULLES INTERNATIONAL	AMERICAN	BRANIFF	NORTHWEST	PAN AM	PIEDMONT	UNITED	U.S. AIR	TRANS WORLD	CONTINENTAL
GATE OPERATION									
1. Use APU (with time and/or climate controls)	X	X	X	X		X		X	X
2. Use GPU	X	X	X			X			X
GATE DEPARTURE									
1. Hold at gate when delays long	X	X	X	X	X	X		X	X
2. Establish position in departure line									
3. Start APU if not operating									
4. Start engines at gate	X	X	X	X	X	X		X	X
5. Start engines during push-back									
6. Start engines after disconnect									
TAXI FOR TAKE-OFF									
1. Use all engines	X	X	X	X		X		X	X
2. Use less than all engines			X	X		X		X	
3. Shut down APU for taxi				X		X			
4. Shut down APU prior to take-off									
5. Shut down APU when airborne									
DELAYS DURING DEPARTURE TAXI									
1. Taxi with less than all engines			X	X		X			
2. Shut down to APU for long delays									
ARRIVAL OPERATIONS									
1. Use optimum runway exit	X	X	X	X	X	X		X	X
2. Use all engines									
3. Use less than all engines	X	X	X	X		X		X	X
4. Start APU for gate arrival	X							X	X
MAINTENANCE AND OVERNIGHT									
1. Use APU									
2. Use GPU								X	
3. Tow aircraft to and from gate									
4. Taxi aircraft except for push-back									

*Does not operate from Dulles International Airport.

X = Actual Procedure Used
No = Procedure Not Used

WASHINGTON NATIONAL AIRPORT

Washington National Airport typlifies a downtown airport at a major city that is land constrained and has exceeded its Practical Annual Capacity (PANCAP) for many years. Because of the constraint on land, DCA has two cross-runways which require the air carrier aircraft to hold for clearance prior to proceeding to the ends of the primary runway (18-36) for take-off. In addition, the heavy traffic requires considerable queuing during the heaviest demands (1600-1900 weekdays).

Figure D.1 presents the airport layout at Washington National Airport. North is to the left. The airport is located between the George Washington Memorial Parkway and the Potomac River. The main runway, 18-16, is 6,870 feet long. There are two cross wind runways, 3-21 and 15-33. They are 4,724 and 5,212 feet long, respectively. Helicopters land in a designated area near the intersection of taxiways K and L.

Airport terminal buildings and passenger gates are located west of the runways. The main terminal is located near the center of the airport. Gates used for boarding and discharging passengers are numbered from south to north. Gate utilization is as follows:

Gate Numbers	Airlines
1-4	Northwest
5-8	Trans World
9-14	American
15-17	U.S. Air
18-23	Eastern
24-28	United
29	Braniff
30-32	Delta
33-35	None
36-38	National (Pan Am)
39-42	Piedmont

The general aviation terminal is north of Gate 42.

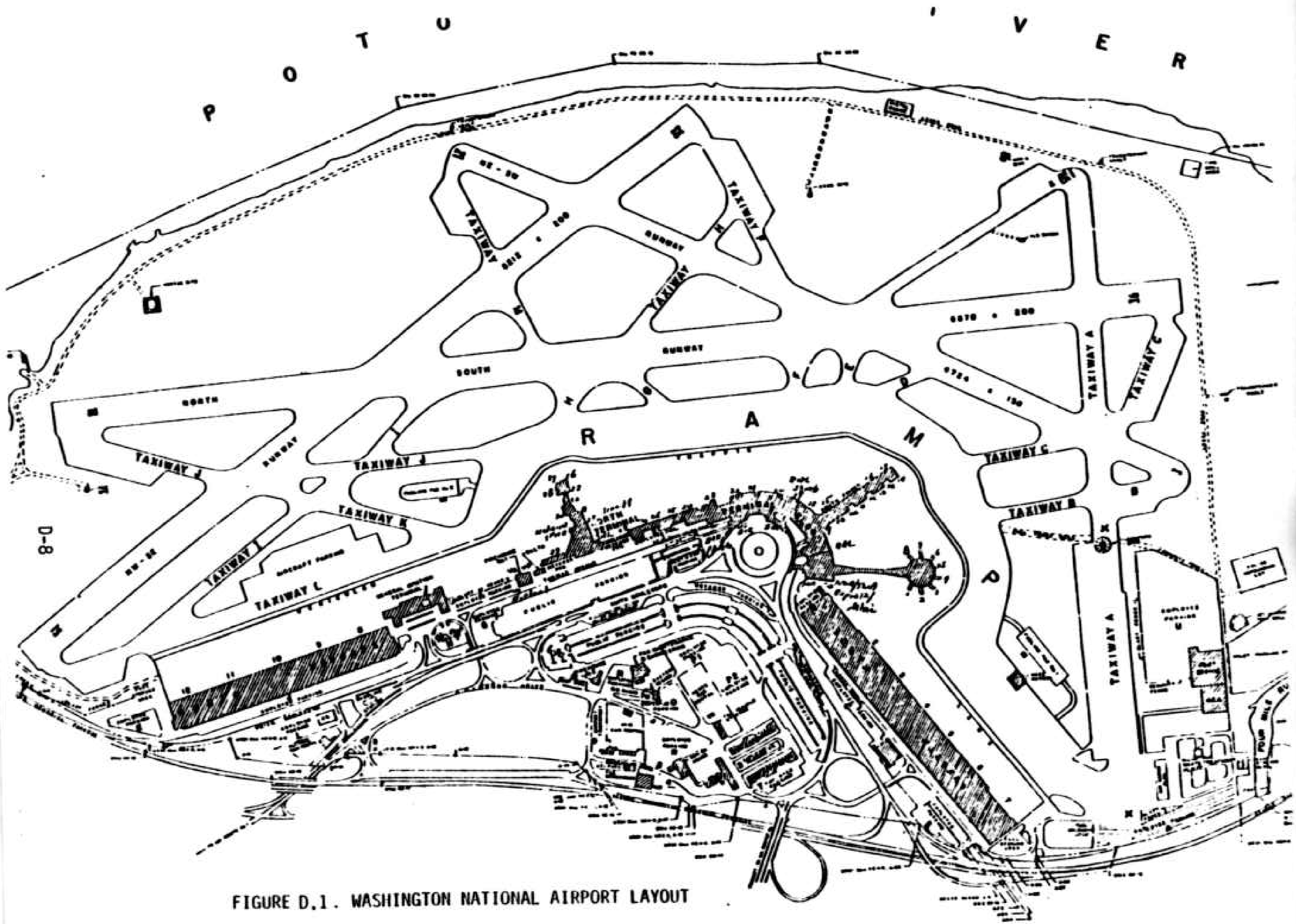


FIGURE D.1. WASHINGTON NATIONAL AIRPORT LAYOUT

American Airlines

Gate Operations. American uses Gates 9 through 14 and operates only B 727 aircraft out of DCA. One GPU is available and is used mainly for stand-by purposes. APU's provide power at the gate and are shut down when aircraft are to be at the gate more than 30 minutes. Aircraft are held at the gate when practical.

Gate Departure Activities. APU's are started approximately 30 minutes before departure when not already operating. Engines are started after push back disconnect.

Taxi to Take-Off Holding Area. Pilots usually start all engines at pushback disconnect but may taxi out with number 2 engine shut down at the pilot's discretion. After pushback, aircraft are approximately 900 feet from the holding area for runway 36, 2000 feet for runway 33, 4200 feet for runway 18, and 6700 feet for runway 15.

Queuing Area Operations. Holding in the queuing area is accomplished with less than all engines operating. More than one engine is rarely shut down because of the need to advance in the queue. APU's are shut down prior to take-off. All engines are operating and checked by the time the aircraft moves to the lead position in the queue.

Arrival Operations. Pilots use the optimum exit when practical. One engine, usually number 3, is shut down one to one and one half minutes after landing. APU's are started to be operating when aircraft arrive at the gate.

Braniff Airlines

Gate Operations. Braniff uses Gate 29 at DCA. GPU's provide needed power except for hot or cold weather when energy is provided by APU's. Aircraft are held at the gate when possible. Aircraft are typically on the ground about 25 minutes.

Gate Departure Activities. APU's are started just prior to departure when not already in use. Engines are started during the push back operation except for icy weather. Therefore, the aircraft is immediately ready to taxi when disconnected from the pushback vehicle and when clearance to taxi is received from the tower. Aircraft move to establish position in departure lines when gates are released for arriving aircraft.

Taxi to Take-Off Holding Area. Taxi to the take-off holding area is accomplished with less than all engines operating subject to pilot discretion and expected departure delay. Runways 15-33 are used for departures when delays on 18-36 can be avoided and when the departing aircraft has the higher performance engines needed for take-off on the shorter runways. Taxi distances to runways 33 and 36 departure holding areas are 2000 and 2800 feet, respectively. Distances for departure on runways 15 and 18 are 2000 feet and 3500 feet, respectively.

Queuing Area Operations. Holding in the queuing area is accomplished with less than all engines operating. All engines are seldom shut down because of the need to advance in the queuing line. APU's are shut down prior to take-off and all engines are operating by the time the aircraft nears the lead queuing position.

Arrival Operations. Aircraft use the optimum exit in most instances. Exit is normally at taxiway "I" for north operations on 36 and at "F" for south operations on 18. Taxi distances in either instance are about 1500 feet. Aircraft taxi to the gate with less than all engines operating.

APU's are started during taxi so that they will be available for use at the gate. Aircraft hold on the apron for gate delays. A long delay is unusual and aircraft taxi to the gate position. Aircraft would be held on the apron on APU power and towed to the gate if a long delay were anticipated.

An aircraft arriving at 7:25 p.m. on Saturday night remains overnight. If another scheduled flight comes through later and needs the Braniff gate, this problem is solved by borrowing a gate from another

airline when practical and by towing the 7:25 p.m. arriving aircraft to a parking area in other instances.

Delta Airlines

Gate Operations. Delta uses Gates 30 and 31. GPU's provide the electrical power needed at the gate. APU's provide the power needed for air conditioning in hot and cold weather and for engine start. Aircraft are held at the gate when possible. Gate space is a problem between 8:00 p.m. and 10:00 p.m. One aircraft has to be moved to make room for other through flights. This problem is often solved by borrowing a gate from Braniff or Pan American. The problem aircraft is towed from one apron position or gate to another to make room for the through aircraft.

Gate Departure Activities. APU's are started just prior to departure when not already in use. Engines are started during push back except for icy weather, and the aircraft is ready to taxi when disconnect from pushback vehicles. Aircraft move to establish positions in departure lines when gates are released for arriving aircraft.

Taxi to Take-Off Holding Area. Taxi to the take-off holding area is accomplished with less than all engines operating, subject to pilot discretion and expected departure delays. Runways 15-33 are used for departures when delays on 18-36 can be avoided and when the departing aircraft has the higher performance needed for take-off on the shorter runways. Taxi distances to runways 33 and 36 holding areas are approximately 2600 and 2900 feet, respectively. Distances for departure on runways 15 and 18 are approximately 3200 and 1800 feet, respectively.

Queuing Area Operations. Holding in the queuing area is accomplished with less than all engines operating. Remaining unstarted engines are operating by the time the aircraft nears the lead position in the queuing line.

Arrival Operations. Aircraft use the optimum exit in most instances. Exit for north operations on 36 is normally at taxiway "I" but is sometimes on runway 15-33. Exit for south operations on 18 is at taxiway "F" when possible but is sometimes on "E" or "D". Less than all engines are used for arrival taxi operations.

APU's are started for gate arrival when needed. Aircraft may hold on the apron for a few minutes until a gate is available, but long gate delays requiring engine shut down and towing to the gate are unusual.

Eastern Airlines

Gate Operations. Eastern uses gates 18 to 23. APU's provide power needed at gates except for long delays when they are shut down. Aircraft are held at gates for long departure delays. DC-9 and B-727 aircraft provide DCA service for Eastern.

Gate Departure Activities. APU's are already in use when the departure activity is initiated. Engines are started during push back except for icy weather and aircraft are ready to taxi when pilots receive the disconnect clear signal. Aircraft move to establish positions in departure lines when gates are released for arriving aircraft.

Taxi to Take-Off Holding Areas. Taxi to take-off holding areas is accomplished with less than all engines operating subject to pilot discretion and expected departure delays. Less than all engine taxi operations were estimated to occur about 25% of the time. Runways 15, 33 and 3 are sometimes used to avoid long departure delays on 18-36 and when departing aircraft have the higher performance needed for use of the shorter runways. Eastern gates are approximately 1500 and 3100 feet from departure holding areas for runways 36 and 18, respectively. APU's remain operating if less than all engines are used for taxi.

Queuing Area Operations. Aircraft hold in queues with less than all engines operating. Remaining engines are started as aircraft approach the

lead position in the queue. Aircraft engines are shut down and APU's are used for power needs when aircraft are trapped in a long queuing delay if it is known that the aircraft will not be moved during the delay.

Arrival Operations. Aircraft use the optimum runway exit in most instances. Exit for north operations on 36 is at taxiway "I."

Exits for south operations are on taxiway "F" when possible, but exits are also made on "E" or "D." Engines are shut down for less than all engine taxi when aircraft have exited the runway. APU's are started to be operating when aircraft approach the gate. Aircraft may hold on the apron for release of a gate, but delays warranting engine shut down and towing to the gate are rare.

Northwest Airlines

Gate Operations. Northwest uses Gates 1 through 4. GPU's are used to provide aircraft power. APU's are used in hot and cold weather to heat or cool the aircraft. Aircraft are held at the gate when long departure delays are expected. Northwest operates B-727 aircraft out of DCA.

Gate Departure Activities. APU's are started just prior to departure when not already in use. Engines are started during push back except when the APU is inoperative and an engine is started at the gate. Aircraft are ready to taxi when the disconnect signal is received from the push back crew. Aircraft move to establish positions in departure lines when gates are released.

Taxi to Take-Off Area. Aircraft typically use all engines for taxi to departure holding areas. Taxi distances are approximately 1800 feet for departures on runway 36 and 4800 feet for departures on runway 18. APU's are shut down prior to take-off. Less than all engines may be used for taxi during delay situations according to the captain's discretion.

Queuing Area Operations. Holding in departure queues is accomplished with less than all engines subject to the captain's discretion when lengthy delays are expected. All engines are operating by the time an aircraft nears the lead position in the departure queue.

Arrival Operations. Aircraft use optimum runway exits when practical. Exit is on "I" for north operations on 36 and "E" for south operations on 18. About 50% of the time less than all engines are used for arrival taxi. Aircraft are held on the apron for gate delays which are seldom long enough to cause pilots to shut down aircraft engines.

Pan American Airlines

Gate Operations. GPU's are used at gates and are often supplemented by APU's. APU's are used in hot or cold weather. Aircraft hold at the gate when practical. B 727's provide Pan American service at DCA.

Gate Departure Activities. APU's are started about 15 minutes before departure when not already operating. Engines are started during pushback, and aircraft are ready to taxi when disconnected from pushback vehicles is completed.

Taxi to Departure Holding Area. Aircraft taxi to departure holding areas using less than all engines according to pilot discretion. Taxi distances are approximately 1,700 and 2,900 feet to runways 18 and 15 and 3,400 and 3,000 feet to runways 36 and 33, respectively.

Queuing Area Operations. Holding in queuing areas is accomplished with less than all engines operating. All engines are seldom shut down because of the need to advance in queues. The last unstarted engine is started and operating before the aircraft advances to the lead position in a queue.

Arrival Operations. One engine is shut down one to one and one half minutes after landing. Optimum runway exits are used when practical. APU's are started for arrival at the gate.

Piedmont Airlines

Gate Operations. APU's are used at gates because of a lack of GPU's. Aircraft are held at gates for departure delays when practical. Piedmont operates B 727 and B 737 aircraft.

Departure Activities. Engines are started after pushback disconnect. All engines are usually started, but only two B 727 engines are started if delays are expected in a departure queue. Pilot discretion determines use of the less than all engine option.

Taxi to Departure Holding Areas. B 727 aircraft taxi to departure holding areas using less than all engines according to pilot discretion. Taxi distances to runways 18 and 15 are 1700 and 2600 feet, respectively. The distances to runways 33 and 36 are 3100 and 3500 feet, respectively.

Queuing Area Operations. Holding in queuing areas is accomplished with less than all engines operating at the pilot's discretion. The need to advance in queues prevents shutting down all engines. All engines are operating and checked by the time aircraft advance to the lead position in a queue.

Arrival Operations. Pilots use optimum exits to the extent practical. One engine is shut down one to two minutes after landing except for B 737's. APU's are started for gate arrival.

Trans World Airlines

Gate Operations. TWA operates B 727 and DC 9 aircraft out of Gates 5 through 8 at DCA. GPU's are used at the gates but are supplemented by APU's in hot and cold weather. Aircraft are held at the gate when practical.

Gate Departure Activities. APU's are started when not operating and engines are started during pushback except for icy weather.

Taxi to Take-off Holding Areas. All engines are usually started for departures on runway 36. Subject to pilot discretion, B 727 aircraft may taxi to the runway holding area with one engine shutdown. Taxi distances are 1100 and 2400 feet to runways 36 and 33 and 4300 and 5800 feet to runways 18 and 15.

Queuing Operations. Holding in queuing areas is accomplished with one engine shutdown. All engines are operating and checked by the time the aircraft advances to the lead position in the queue. APU's are shut down prior to take-off.

Arrival Operations. One engine is shut down on B 727 aircraft about one minute after landing. One engine may also be shut down on DC 9 aircraft subject to pilot discretion.

United Airlines

Gate Operations. GPU's are used as much as possible. APU's are started about 5 minutes before departure but will operate longer in hot and cold weather. Aircraft are held at the gate when practical. United operates B 727 and B 737 aircraft out of DCA. United uses gates 24 through 28.

Gate Departure Activity. Engine starts begin during push back or after disconnect according to pilot discretion. All engines are usually started but pilots may decide to shut one down or to delay its start if long delays are anticipated.

Taxi to Take-off Areas. B 737 aircraft use all engines for taxi, but one B 727 engine may be shut down or left unstarted for taxi. Taxi distances are 2100 and 1700 feet to runways 36 and 33 and 2500 and 4000 feet to runways 18 and 15, respectively. All engines are often needed for initial taxi because of congestion in areas along the terminals.

Queuing Operations. Engines are shut down for queuing delays according to pilot discretion. All engines are rarely shut down because of the need to advance in queues. APU's are restarted if necessary for queuing operations.

Arrival Operations. One B 727 engine is usually shut down one to one and one half minutes after landing. B 737 engines are not shut down. Runway exit choices are limited at DCA because of the short runways, but the optimum exits, "H" or "I" for landings on 36 and "F" or "E" for landings on 18 are used when practical. APU's are started for gate arrival when needed.

U.S. Air

Gate Operation. U.S. Air uses gates 15 through 17. APU's are used at the gates. U.S. Air operates B 727, DC 9, and BAC 111 aircraft out of DCA. Aircraft are held at the gate when practical.

Gate Departure Activities. Aircraft engines are started by the time aircraft are disconnected from push back vehicles.

Taxi to Take-off Holding Areas. APU's are shut down for taxi. Aircraft usually use all engines for taxi but pilots may shut down one B 727 engine for delay situations. Taxi distances are 1300 and 1500 feet to runways 36 and 33 and 3400 and 5000 feet for runways 18 and 15, respectively.

Queuing Operations. One or more engines may be shut down, and APU's may be restarted for long delays in departure queues. The decision is subject to pilot discretion. All engines are rarely shut down because of the need to advance in queues. All engines are operating and checked by the time the aircraft advances to the lead position in the queue.

Arrival Operations. Engines are shut down for taxi one and one half to two minutes after landing. BAC 111, DC 9, and B 727 aircraft taxi in with one engine shut down when practical. APU's are started for gate operations.

DULLES INTERNATIONAL AIRPORT

The airport layout for Dulles International Airport enables efficient operations and provides little opportunity for altering airport design or operating practices for the purpose of conserving fuel. Two parallel 11,500 foot north-south runways are located on either side of parallel taxiways connecting the runways. Each runway has 6 diagonal exits, 3 for north and 3 for south landings as shown in Figure D.2. Aircraft can use an optimum route, and the lack of congestion prevents delays. Aircraft that do not need the long runways may take-off from convenient points along the runway. Also, taxiways are sometimes used as runways by the very small aircraft.

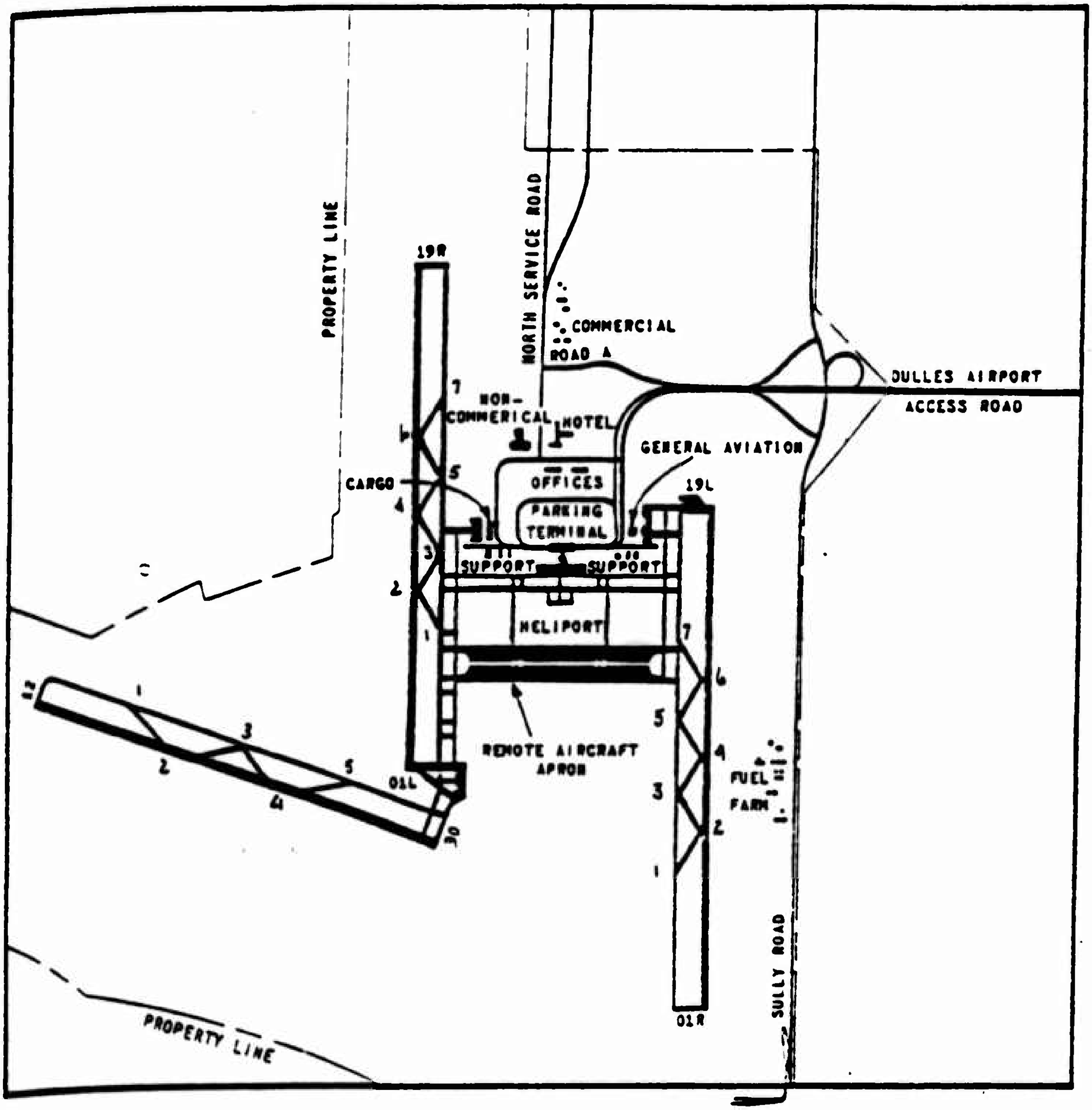
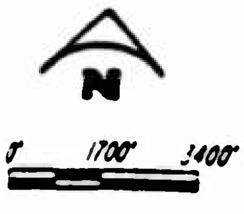


FIGURE D.2. DULLES INTERNATIONAL AIRPORT LAYOUT



Use of the 10,000 foot cross wind runway involves an unusually long taxi activity. The runway is located more than a mile from the connecting taxiways. An additional one to two miles must be covered if take-off is to the southwest on 12 and if landings are to the northwest on 30.

Delay situations at Dulles generally involve some special event that attracts large numbers of general aviation aircraft. Also, commercial aircraft are diverted to IAD because of the excellent landing aids when other airports such as Washington National are closed due to inclement weather.

Interviews with pilots using IAD indicated that taxi for departure with less than all engines operating is rarely practical for the larger aircraft. For arrival, pilots generally shut down one engine on DC-10 and L-1011 type aircraft and two engines on the B-747, B-707 and DC-8 aircraft.

Pilots operating aircraft types that also operate out of Washington National Airport use essentially the same practices as they do at Washington National. They shut down one engine for arrivals. Less than all engines are started for departures when delays or extended taxi times are expected.

Aircraft are not pushed back from the gate at IAD and begin to taxi from parked positions. Aircraft are held at their parking positions when airspace delays occur, and delays for airport congestion are unusual.

Gate Operations at Dulles

Airline parking positions or gates at Dulles are located along two lines connecting the two north-south runways. The positions are numbered from east to west with odd numbers on the north side nearest the tower and terminal. The two rows of gates are separated by three buildings housing operations activities.

Mobile lounges transport passengers from the terminal to aircraft. The original vehicles are referred to as mobile lounges. These vehicles seat 72 passengers and can hold 102. The newer vehicles are called Plane Mates.

They seat 102 passengers and hold 150. Both units use about 2 gallons of fuel per round trip to the plane.

The lounges used 117,472 gallons of diesel fuel in 1979.

Pan American Airlines uses Gates 1 through 4, but mainly Gate 3. Ground Power Units are not available and APU's are used. APU's are started 10 minutes before departure if not already in use. They remain on if turn around times are less than 45 minutes.

Trans World Airlines uses Gates 5 through 8 and have fixed electrical power in the ground at Gates 7 and 8. APU's that have been shut down for less than 5 minutes are not restarted for at least 30 minutes except for the B-747's. APU's on TWA B-747's are not restarted for at least one hour. These waiting periods are maintenance precautions.

United Airlines uses Gates 9 through 15 (there is no gate 13) and has fixed electrical power in the ground at several positions. Ground Power Units are also available.

Continental Airlines uses Gates 16 and 18. GPU's are available.

Northwest Orient Airlines uses Gates 17 and 19. GPU's are available.

Braniff Airlines uses Gates 20, 21, and 23, and GPU's are available.

American Airlines uses Gates 24, 25, 26, and 27. GPU's are available.

Air France uses Gate 28.

British Airways uses Gate 30.

Taxi Operations at Dulles

Aircraft movement is clockwise around the parking areas. A complete trip around the area is 10,000 feet but an aircraft facing the wrong way is not required to travel the entire distance. They can taxi from north to south or south to north areas by using either of two passages between the three buildings. However, the B-747's are not permitted to use the passages when the lounges or other vehicles occupy the passage. This limit is due to the B-747 jet blast hazard and is a safety precaution.

When traffic permits, the clockwise taxi rule is not enforced and aircraft are permitted to take the shortest and most direct route to runways or gates.

Runway Utilization at Dulles

Airport layout and normal traffic patterns utilize runways one right and nineteen right for landing and one left and nineteen left for take-off. This results in the shortest taxi distance in directions parallel to the runways. However, the distance between runways is great, and a gate can be much closer to one runway than another. Airlines with gates close to one runway may need to taxi 4,000 to 5,000 feet farther if they use the other runway. Taxi distances can be minimized when airlines can use the runway closest to their gate positions for landing as well as for take-off. Exceptions are permited when traffic is light.

Landing in either direction on a preferred runway when wind speeds are low could affect taxi time and fuel used. Of course, any fuel savings on the ground would be negated by additional fuel consumption in the air, if the aircraft were to stay in the air longer in order to utilize the preferred runway. The runway which minimizes flight duration is, therefore, generally preferred over the runway which provides the shortest taxi distance.

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ANNEX 1 to APPENDIX D

INTERVIEWS WITH AIRLINE PERSONNEL

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ANNEX 1 TO APPENDIX D

MEETINGS AND TELECONS

ANNEX 1 TO APPENDIX D
(Continued)

SUBJECT: Fuel Conservation Meeting and Telecon - American Airlines

DATE: 4 November 1980 plus 18 December Telecon

PLACE: Dulles International Airport

PERSONS PRESENT OR CONTACTED:

1. Mr. Jerry Harlow, Ramp Supervisor
2. Mr. John Woo, ORI Consultant at meeting.

Notes on Operating Procedures and/or Policy:

1. Aircraft are held at the gate.

2. Less than all engine taxi is at the discretion of the pilot but aircraft taxi-in on less than all engines.

3. GPU's are used for power needs for B-707 aircraft.

4. APU's are used on B-727 and DC-10 type aircraft and are started as aircraft approach the gate.

5. APU's are started 15 to 20 minutes before departure if not already operating.

Information Sources:

1. Tulsa Oklahoma.

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SUBJECT: Fuel Conservation Telecon -- American Airlines

DATE: 12-24 November 1980

PERSON CONTACTED:

1. Fred Moyer, Director-Maintenance, DCA -- 892-7770
2. Captain Koester, Director-Flight Operations, DCA -- 892-7870

Notes on Operating Procedures and/or Policy

1. American has one stand-by APU.
2. APU's provide electric and pneumatic power needed at gate positions except when aircraft are to be at the gate for a time more than 30 minutes.
3. Pilots usually start all engines at pushback but may taxi-out with #2 off at pilot direction.
4. Pilots taxi-in with one engine, #3, shut down.
5. Idle power, 55%, is normally enough to sustain taxi speed. RPM thrust limits must not be exceeded and can be a problem with two engine starts.

Action

Contact Koester for meeting after he returns on 26 November 1980.

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SUBJECT: Fuel Conservation Telecon: American Airlines

DATE: 1 December 1980

PLACE: ORI, Inc.

PERSON CONTACTED:

1. Captain Koester, Flight Operations -- 892-7870

Notes On Operating Procedures and/or Policy

1. APU's are turned off about one minute before take-off.

2. One of his pilots believes that B-727 idle speeds can be reduced 5 to 10%. The pilot also understands that fuel flow would be reduced the same amount. The result would be a $5,000 per day or $1,800,000 per year savings if true.

3. AAL taxis to gate on 2 engines.

4. APU's are shut down at gates if delays (ground time) are to be more than one hour.

5. All three engines on B 727's are started for north take-offs except when delays are expected in the departure line. Two engines are started for soutn take-offs. All engines are operating and checked shortly before clearance is given for take-off.

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SUBJECT: Fuel Conservation Telecon -- Braniff Airlines

DATE: 25 November 1980

PLACE: ORI, Inc.

PERSON CONTACTED:

1. Captain Paul Sterbenz -- (214) 574-5234
2. Captain George Gillette -- (212) 632-1560

Notes on Operating Procedures and/or Practices

1. Captain Gillette was not in when called. He is Regional Director of Flight. His office advised contacting Captain Sterbenz in headquarters.
2. APU's are used at gates at DCA.
3. Two engines are started at pushback (except for snow, etc.) for take-offs on 19. Three are started for departures on 30.
4. Third engine started when approaching runway.
5. Pushback crews should but do not always head aircraft in taxi direction. Turning uses more fuel and increases jet blast.
6. Captain Sterbenz uses power burst for about 10 seconds to start from stop. Fuel flow is increased to 2,000 lb/hr = 33 1/3 lb/min.

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SUBJECT: Fuel Conservation Telecon, Calgan Airways at DCA

DATE: 16 December 1980

PERSON CONTACTED:

1. Hershall Connel, Manager.

<u>Notes on Operating Procedures and/or Policy</u>:

1. Calgan operates a Beech 99 plus some smaller aircraft.
2. GPUs are used about 60% of the time. Aircraft have no APU's and must start on battery power if GPU is not available.
3. They hold at the gate for all anticipated delays.
4. They taxi with all engines for departure and arrival.

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SUBJECT: Fuel Conservation Telecon - Continental Airlines

DATE: 12 December 1980

PLACE: ORI

PERSON CONTACTED:

1. Dave Jaeger, Operations Supervisor Dulles, 471-7056.

Notes on Operating Procedures and/or Policy:

1. GPU's are used if aircraft are to be on the ground more than one hour.

2. APU's are used in hot and cold weather

3. APU's are started 15 to 20 minutes before departure.

4. All engines are started at the gate.

5. Aircraft hold at the gate for delays.

6. Aircraft (B-727s) taxi out on all engines and arrive with one or two engines shut down. Two engines are off and taxi is on one engine if the gate can be approached straight in from the east.

Information Sources:

1. Continental has created a new position called a load planning specialist. The objective is to save fuel. They load for aft cg position and minimize fuel loads.

2. Reports are sent to headquarters where considerable information is available with respect to fuel conservation.

Action:

1. Contacts for fuel conservation information:

   a. Bob Buel, (213) 646-4876
   b. Bill Miller, (213) 646-3230

2. Address is:

   Continental Airlines
   Los Angeles International Airport
   Los Angeles, California 90009

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SUBJECT: Fuel Conservation Meeting -- Delta Airlines

DATE: 7 November 1980

PLACE: Delta Airlines

PERSON CONTACTED:

1. Jack Schneider, Station Manager -- 521-4242
2. Alexander Barclay, Assistant Manager -- 521-4242

Notes on Procedures and/or Policys

1. Delta is considering less than all engine taxi.
2. APU's are shut down when possible -- no fixed practice on limit.
3. Use GPU for overnight power needs.
4. Delta is considering diesel powered units for electrical and pneumatic needs.
5. Has to move one overnight flight from gate to permit use of gate by later through flight.
6. Engines are started and operating by time crew receives push back disconnect signals.
7. Delta has pulled out of Dulles.

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SUBJECT: Fuel Conservation Telecon - Delta Airlines

DATE: 5 December 1980

PLACE: ORI

PERSON CONTACTED:

1. Captain Smith, Vice President, Flight Operations
2. Captain Sue Davis, Flight Operations

Notes on Operating Procedures and/or Policy:

1. A standard practice for Delta is to taxi out and in with less than all engines operating at idle.
2. Pilots may taxi with one engine at their discretion.
3. Engines are started after aircraft are disconnected from push-back vehicles.
4. APU's are shut down when last engine is started.
5. Engines are shut down for less than all engine taxi when aircraft have cleared the runway.
6. APU's are restarted and one or more engines are shut down for long taxi and gate delays.
7. Delays for departures on 18 and 36 are about the same for Delta.

Policy Documents and Data:

1. Fuel alert bulletins will be sent to illustrate Delta concern for fuel conservation.

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SUBJECT: Fuel Conservation Meeting -- Eastern Airlines

DATE: 24 November 1980

PLACE: Eastern's Flight Operations Office - Hanger 1 at Washington National Airport

PERSON CONTACTED:

1. Captain L. P. Anderson -- 979-9247

Notes on Operating Procedures and Policys

1. "Taxi-in" is with less than all engines including DC-9. Brakes are used to control taxi speed.

2. APU's are started when an engine is shut down.

3. APU's remain operating for power needed at gate positions but are shut down when turn around times are long.

4. Aircraft engines are started by the time pilots get the disconnect clean signal.

5. "Taxi-out" with less than all engines occurs about 25% of the time at DCA. APU's remain operating if all engines are not started.

6. Engines are shut down and APU's restarted if an extensive delay is expected and aircraft are already in take off holding area.

7. Some delays in departure holding areas are longer than necessary because preceding pilots did not leave room to pass and/or because ground control gave clearance for too many aircraft to cross into the holding area.

Policy Documents or Data

1. Eastern tests at Fort Lauderdale, Florida were recently completed to evaluate fuel savings if GPU's were immediately plugged in. They saved 825 gallons in 30 days.

2. Eastern estimates that 1¢ a gallon per aircraft per day amounts to $10,000,000 per year.

3. Taxi-in and taxi-out fuel is reported by captains on the company radio. These terms refer to the amount of fuel on board for arrival and the amount of fuel for departure, and do not refer to the amount of fuel used to taxi-in or taxi-out.

4. Pilots are given minimum and maximum fuel needed for each flight. Pilots select amounts between these two limits. They are aware of the costs associated with transporting unneeded fuel and make their decision in terms of cost as well as safety considerations.

SUBJECT: Fuel Conservation Telecon -- Northwest Airlines

DATE: 25 November 1980

PLACE: ORI, Inc.

PERSON CONTACTED:

1. Ron Akers, Station Manager -- 892-5643

2. Captain Jerry Fredricson, Flight Direction -- (612) 7111 X 2913

   a. Taked to Captain Donald C. DeBolt, Manager Flight Test

Notes on Operating Policies and Procedures

1. Northwest policy is to use GPU's when possible.

2. APU's are shut down after 2 minutes for cooling stabilization.

3. Taxi-in at DCA is on two engines more than 50% of the time.

   a. All engines are needed for sharp turn, 180^{0}, at one gate.

   b. All engines are needed on hot days when ramps are soft.

4. Less than all engine operating decisions are made according to Captain's discretion.

5. Two engine taxi-out at DCA does not pay and is not very practical due to short taxi distances and times.

6. B-727 idle thrust is enough to accelerate to taxi speed when surfaces are hard and level and aircraft are not too heavy.

7. Fuel Management techniques are saving NW $1,000,000 a month.

8. Copies of a May 16, 1980 Flight Standards Bulletin on fuel management are being mailed to James K. Thompson.

9. An educational program is needed. Significant fuel savings in the air are possible if FAA would permit and encourage slower descent speeds at best L/D (lift over drag).

Policy Documents and Data

1.* Northwest Airlines "Flight Standards Bulletin" dated 16 May 1980. This publication describes a series of bulletins that have been updated including Bulletin Number 2-80 on fuel conservation.

2.* Northwest Orient Airlines "Flight Standards Bulletin" 2-80 dated 15 May 1980. This bulletin on fuel conservation covers procedural matters pertaining to air and ground operation. Data on page 3 shows APU fuel consumption as follows when running under electrical and air conditioning loads.

B-727's -- 40 gallons/hour
DC-10's -- 60 gallons/hour
B-747's -- 145 gallons/hour

SUBJECT: Fuel Conservation Telecon -- Pan American Airlines

DATE: 26 November 1980

PLACE:

PERSON CONTACTED:

1. Dave Ramsburg, Maintenance at Dulles -- 661-8166
2. Steve Cook, Lead Mechanic at DCA -- 979-9722
3. Bill Pilchuck, Maintanance Supervisor, DCA -- 979-9722
4. Jack Chambliss, Maintenance Manager, DCA --
5. Charles Jummel, Operations Manager, Dulles -- (703) 661-8166

<u>Notes on Operating Procedures and/or Policy</u>

1. Dulles

   a. Pilots start all engines at the blocks on B-747's.

   b. B-747's taxi-in on 2 engines.

   c. APU's are started 10 minutes before departure time if they are not already operating.

   d. APU's remain on for 45 minutes or less turnaround times.

2. Washington National Airport

   a. They have three GPU's but can't rely on them.

   b. GPU's are used as much as possible and are hooked up as soon as aircraft arrives at the gate.

   c. Pilots are advised when GPU's are started when aircraft approaches the gate.

   d. APU's are started 15 minutes before departure if not already operating.

   e. APU's are used to control inside temperatures and are used in hot or cold weather. Also, they are also used to insure that cockpit instrumentation is warm for departures.

f. Pan American at Washington National has operating bulletins and procedures.

3. FAA letter referred to Corporate Headquarters: call Captain William Erkes.

SUBJECT: Fu: Conservation Telecon - Pan American Airlines

DATE: 5 December 1980

PLACE: ORI

PERSONS CALLED:

1. Captain Erkes, Vice President, Operations and Engineering, (212) 632-6126
2. Captain Roy Strong, Manager of Flight Engineering (305) 874-2446.
3. Captain Dick Hart, Director of Operations and Engineering, (212) 632-5440.
4. Captain Tom Egan.

Notes on Operating Procedures and/or Policy:

1. Fuel conservation has been a subject of increasing concern and interest to Pan American for years. Information is included in manuals and notices.

2. Less than all engine taxi is subject to pilot discretion but is not encouraged for four engine aircraft at heavy gross weights. Pilots did taxi in with one B-747 engine shut down but now may shut down two engines.

3. B-727 and DC-10 aircraft may taxi and hold on one engine and APU.

4. Gate limitations at DCA cause delays for arriving aircraft. For long delays, engines are shut down and aircraft are towed to gates while using APU power.

5. Aircraft are held at the gate when possible.

6. Engines are started during push back except for slippery weather.

7. APU's provide heating and cooling (air conditioning) during hot and cold weather.

8. Pan American has no APU restart time limit.

Policy Documents and Data:

1. [illegible] American Taxi Fuel Allowance data will be forwarded.

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SUBJECT: Fuel Conservation Telecon - Piedmont Airlines

DATE: 1 December 1980

PLACE: ORI, Inc.

PERSON CONTACTED:

1. Captain Sharp, Vice President -- (919) 767-5371

Notes on Operating Procedures and Practices

1. Piedmont issued a Fuel Conservation Bulletin about 2 years ago. It is being revised and updated information will be provided to personnel in a few months. A copy will be sent to James K. Thompson.

2. APU's are used at DCA because of a lack of GPU's.

3. All engines are started when push back has been completed. This prevents undesirable strain on tugs. They would start only 2 B 727 engines if they expect a departure congo line.

4. Engines would be shut down if a long delay is encountered in departure hold operation.

5. APU's are shut down about 2 minutes after aircraft are airborne.

6. B-727 idle thrust is often adequate for acceleration to taxi speed when three engines are operating at idle using about 1200 pounds of fuel per hour.

7. B-727 thrust is increased up to about 2400 pounds per hour on each engine when two are used for taxi operation. Power is reduced to about 1500 pounds fuel per hour after about 15 seconds.

8. Pilots will hold at gate for expected long delays except when aircraft must be moved for an arrival.

9. Tugs are used to tow aircraft to gates in the morning.

10. Taxi with less than all engines operating is not practical in hot weather when heavy aircraft are operated on soft surfaces or when taxi routes are uphill or uneven.

11. All engines are used when runways are slippery.

Action

1. Review Fuel Conservation Bulletin when it arrives.

SUBJECT: Fuel Conservation Meeting -- Trans World Airlines

DATE: 4 November 1980 at 1:30 p.m.

PLACE: TW Conference Room at Dulles International Airport (IAD)

PERSONS PRESENT:

1. TW

   a. Mr. K. P. Erne, Manager of Maintenance (703) 471-7075

2. ORI, Inc.

   a. James K. Thompson
   b. John C. H. Woo

Notes on Opera' ıg Practices and/or Policy

1. TW operates only L-1011's out of Dulles.

2. Pilots normally shut down #2 engine for taxi to the gate after engine speed has been reduced to idle for at least one minute except when runways are slippery. Under slippery conditions, #2 engine is not shut down.

3. Engines are started when all cargo and cabin doors are closed and door lights are out and when no gate hold procedure is in effect.

4. All engines are normally started immediately at IAD because of the short taxi times and because the aircraft are heavy for longer flights and need more taxi power. The time required to complete check lists is not much less than taxi-out times.

5. Idle power settings may not be enough to maintain desired taxi speeds at IAD and high settings are used for taxi as well as for accelera.ion to taxi speed.

6. Fuel load planning is done for pilots. Economics dictate minimum fuel-loads to reduce aircraft weight.

7. APU operation is kept to a minimum.

8. APU's are not shut down unless 30 minutes will elapse before re-starting is required. B-747 APU's that have been shut down for at least 5 minutes may not be restarted for one hour or more. (TW does not operate these aircraft out of Dulles).

9. APU operating guide lines define temperature conditions for which APU operation is and is not permissable.

10. L-1011 APU's are set on "minimum mode' when needed for ground servicing.

11. TW keeps an APU utilization record. The data is forwarded to headquarters and includes information on operating times, reason for operation, and fuel used.

Policy Documents and Data

1. An advisory booklet on fuel conservation was issued to all flight deck crew members. It is called the "Red Book" and is dated 11 January 1980.

2. An advisory letter dated 16 May 1980 was sent to all airport service and maintenance managers to provide APU operating guide lines.

Action Notes

1. A copy of the "Red Book" was made available on 13 November and must be returned as soon as possible. (It was borrowed from a crew member).

SUBJECT: Fuel Conservation Meeting -- United Airlines

DATE: 18 November 1980 at 1:30 p.m.

PLACE: Flight Operation Offices, Hanger 3, Washington National Airport

PERSONS PRESENT:

1. United Airlines

   a. Captain Pat Nugent -- 892-7480
   b. Bob Goodman --
   c. Larry Diehl -- 892-7409

2. ORI, Inc.

   a. James Bauchspies
   b. James K. Thompson

<u>Notes on Operating Practice and/or Policy</u>:

1. Ground Power Units (GPU's) are used as much as possible.

2. Air Power Units (APU's) are not started until about five minutes prior to departure from gate position.

3. Engine starts begin about the time of disconnect from push back equipment.

4. Taxi-out on less than all engines is at the pilot's discretion and occurs no more than 25% of the time at DCA.

5. The objective is to have all engines operating and to complete engine checks just before ATC clearance is given.

6. Idle Power with less than all engines operating is normally adequate to keep aircraft in motion. Brakes are used to control speed.

7. Thrust increases to start an aircraft in motion and to accelerate to taxi speeds are limited by jet blast considerations and may require use of all engines. B-727's operated by United Air use 62% RPM as the limit.

8. Uneven taxi ways and aprons adversely affect breakout and taxi thrust requirements and sometimes preclude use of less than all engines. B-737's seldom taxi-in or out at DCA on one engine.

9. Engines are turned off when delays occur during taxi-out and when air traffic advises the captain that there will be an extended period, say fifteen minutes or more, before the aircraft can be moved closer to the take-off point. Frequent position relocations during taxi-out usually preclude engine shut down They seldom know how long the delay may be.

10. Pilots must stop prior to moving onto or across runways and wait for air traffic clearance even though an immediate OK is expected and received. Extra fuel is used because of such delays.

11. B-727's usually taxi-in at DCA and IAD on two engines.

12. All engines are used when taxiways are slippery.

13. APU's on United aircraft can be restarted without any delay for cool down.

14. Programs to train personnel concerning fuel conservation aspects of their own activities have been effective.

15. Air traffic procedures to reduce the number of airplane stop and start operations on the airport would conserve fuel at DCA.

16. Aircraft positioning in the line for take off and airport taxiway designs to improve aircraft ability to move past those delayed by airspace congestion would conserve fuel at DCA.

Policy Documents and Data

1. Pages 70 and 71 of a Flight Operations Manual, dated 11-7-80 were made available. These pages show 1980/81 winter time fuel allowances and taxi times associated with various aircraft types and airports. Different values are used for other seasons and depend upon historical data. Longer taxi times and greater fuel allowances are believed to be associated with summer time operations. The data assumes that all engines are operated during taxi. Data for other seasons can be obtained from Uniteds dispatch headquarters.

2. B-727 Flight Manual Handbook, Bulletin #67, dated 7-17-80 was made available to illustrate attention being given to fuel conservation matters. The bulletin pertains to two engine start and taxi and one pack operation for fuel conservation. It indicates, for example, that both air conditioning packs should be operated from engine bleed air during taxi. This results in less fuel flow until engine power is increased to more than idle, which then causes a relative increase in fuel flow. The bulletin describes a number of factors that must be considered when captains make decisions involving fuel conservation and two engine operation.

3. Notice to all SFO B-727 captains, dated 10-10-80. This notice provides advice to pilots concerning delayed start of the 3rd engine.

4. Notice to all SFO B-737 pilots, dated 10-15-79. This notice discussed fuel conservation practices for B-737 aircraft for air and ground operations.

5. Notice to all SFO DC-10 flight crews, dated 12-19-79. This notice describes fuel conservation ideas developed by United and McDonnell-Douglas personnel for the DC-10.

6. Statistical data on APU use has been obtained but has not been broken out by airport.

7. Data concerning taxi-out and taxi-in operational times are sent to United headquarters offices and may be available.

Action Notes

1. Captain Nugent expects to call James Thompson on November 20 or 21 with respect to additional data that may be available.

2. Contact United Engineering and Operations offices to determine availability of technical data on delay and fuel conservation action benefits.

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SUBJECT: Fuel Conservation Telecon -- United Airlines

DATE: 1 December 1980

PLACE: ORI, Inc.

PERSON CONTACTED:

1. Captain Bill Brum, DCA

2. Captain Gordon McKinzie, Manager of Fuel (312)

Notes on Operating Procedures and/or Policy

1. United Flight Operation Manual presents 1980/81 winter fuel allowances for taxi operations at major airports for 6 aircraft. Information had been requested concerning data sources and allowances for other seasons.

   a. Allowances are based upon historical taxi time data with all engines idle for the indicated taxi times.

   b. Allowances for the summer season are available and will be sent to James K. Thompson by Captain McKenzie. Captain McKenzie is the fuel expert for United.

2. United B-737's at DCA taxi-out on 2 engines and in on one engine except for aircraft congested times and slick runways when all engines are operated.

3. United DC-8's taxi-in and out on 2 engines.

4. United has a major campaign to reduce APU use.

5. Captain McKenzie noted that bleeding air from engines when operating at idle speeds reduces thrust and fuel consumption. Therefore, APU's may be shut down saving APU fuel consumption during taxi as well as reducing aircraft fuel consumption. The reduction in thrust is helpful in that it reduces the braking needed to control taxi speed.

6. Captain Brum has been considering fuel consumption during 2 and 3 engine taxi on B-727's. Idle fuel consumption is 1200 pounds per hour per engine (20 lb/minute). At some airports, Baltimore for example, three engines are needed to push the aircraft up sloping surfaces. The alternative is to add power when 2 engines are used to taxi. Fuel flow rates are about the same. Two engine taxi benefits can be negated when taxi requires as much or more power than all engine idle thrust. The same is true for aircraft unstick for which brakes are released and power is added until the aircraft begins to move.

7. Three minutes is a reasonable time to allow for engine start and check procedures.

<u>Policy Documents and Data</u>

1. Taxi fuel allowance data is being sent for summer seasons.

SUBJECT: Fuel Conservation Telecon -- US Air

DATE: 14 November 1980

PERSON CONTACTED:

1. Captain Nash, Flight Operations -- 892-7100

Notes on Operating Procedures and/or Policy

1. Aircraft taxi-in with less than all engines:

    a. BAC-111 (yes)

    b. DC-9 (yes)

    c. B-727 (did not know)

2. Engines are shut down 1½ to 2 minutes after they are stabilized at idle.

3. APU's are started and operating by the time the aircraft arrives at ramp area.

4. Single engine idle thrust is enough to keep aircraft rolling.

5. APU's remain on unless aircraft are to be on the ground more than 30 minutes.

6. All engines are started by the time pushback is completed.

7. Taxi out is with all engines operating and APU's shut down.

8. Engines are shut down and APU's restarted if there is an expected long delay.

9. Some delays result in holding areas because preceding aircraft did not pull over into holding areas. For runup and are delayed for lack of airspace clearance. The following aircraft could be cleared for take off but cannot pass the delayed aircraft.

Policy and Document Data

1. Records of fuel burn by equipment are compiled.

2. Operating practices are updated as fast as practical to incorporate fuel conservation options.

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SUBJECT: Fuel Conservation - United Airlines Papers and Telecon

DATE: 10 December 1980

REFERENCE: 2 December 1980 Letter to James K. Thompson from Gordon A. McKenzie, Manager of Fuel and Performance Control Flight Operations

Notes on Operating Procedures and/or Policy:

1. Data being prepared for inclusion in United's Flight Operations Manual for 1981 Summer Taxi fuel allowance determinations were enclosed. The data show taxi-in and out times at various airports for six aircraft and for different flight times.

   a. Washington National Taxi Times in Minutes:

	TIME	B-727	B-737
1	0:00 to 15:59	9 out-3 in	8 out-3 in
	16:00 to 21:29	12 out-3 in	11 out-3 in
	21:30 to 23:59	10 out-3 in	9 out-3 in

   b. Dulles International Airport Taxi Times in Minutes:

Aircraft:	B-747	DC-10	DC-8 & B-727	B- 737
Taxi Times:	8 out -6 in	7 out-6 in	7 out-5 in	6 out-4 In

2. Taxi-out time begins when brakes are released for pushback at Washington National. It begins at Dulles International when brakes are released for taxi. Engines are started after brake release at DCA and before brake release at IAD. Taxi-out time ends at both airports when the aircraft lifts off and the gear retracts. Taxi-in times begin during the landing roll when aircraft weight is on the landing gear and ends when the brakes are set. The information is communicated via radio and automatic microswitches.

3. Data available from a number of years are used to determine the indicated taxi times. The times are more of a median value than a mathematical average and are adjusted to cover anticipated new circumstances such as construction and resurfacing activities. Judgment is a factor in the determination.

4. Pages from an April 1980 publication called "cockpit" were included in correspondence. The pages from this publication showed potential fuel savings that could result from each of three operating strategies: a) A taxi-out strategy using the following assumptions could save 8,026,276 gallons of aviation fuel per year:

a. All engines are started but one engine is shut down after the first minute, then

b. The aircraft taxis-out on remaining engines at no increase in thrust, then

c. The stopped engine is restarted 2 minutes prior to take-off.

b) One engine is shut down when departure delays reach 10 minutes and restarted 2 minutes before take-off. This strategy would save 3,091,186 gallons of fuel per year for United.

c) Shuting down one engine as soon as the runway is cleared on arrival would save 4,919,409 gallons of fuel per year.

SUBJECT: Fuel Conservation - U.S. Air

DATE: 13 November 1980

PLACE: Washington National Airport

PERSONS CONTACTED:

1. Mr. John Rogerson, Maintenance Supervisor, 892-7155
2. Mr. John Woo, ORI Consultant

Notes on Operating Procedures and/or Policy:

1. APU's are shut down if delays or stay on the ground is much more than 1/2 hour.

2. Pilots usually shut down one engine for taxi.

3. Division in Pittsburgh maintains records on energy usage, flight operations and APU operating times.

4. Procedures are published in operating manuals.

Action:

See Captain Nash.

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SUBJECT: Runway Utilization at Dulles, Telecon

DATE: 4 December 1980

PERSON CONTACTED:

1. L. C. Hartman: FAA, Dulles Tower, 471-1270

2. Henry Mahns: FAA DCA and IAD Planning, 557-1136

Notes on Operating Practices and/or Policy

1. The Master Plan for Dulles International Airport has information on arrival and departure runway utilization at Dulles. The information is on Page 4-10.

2. Data available from Lyle Hartman indicates utilization in terms of arrivals for 1979 as follows:

Runway	% of Arrivals	% of IFR Arrivals
1R	30	40
1L	20	15
19R	20	20
19L	20	15
30	5	0
12	5	10

3. IFR arrival data includes air carrier landings in nice weather

4. Runway 1 right is approved for Category 2 and 3A conditions, 1200 and 700 RVR, respectively, RVR is runway visual range.

5. Runway utilization is not affected by snow and ice except for the availability of cleared surfaces.

6. 1 STOL and 19 STOL runways have been decommissioned.

7. Other runways used in rare heavy traffic situations.

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SUBJECT: Runway Utilization at Washington National

DATE: 3 December 1980

PERSONS CONTACTED:

1. W. S. (Bill) Canty: ATC Operations, 557-2861

Notes on Operating Practices and/or Policy

1. 1979 Data is available for IFR and VFR arrivals:

   a.

Runway 36	44%	Runway 18	27%
33	21%	15	4.5%
3	1%	21	2.5%
	66%		34%

   b. Helicopters use North Helicopter Pad 100% (near General aviation).

2. Some air carriers use runway 33 for strong crosswinds.

3. North Operation is preferred.

4. North operations are used when ceiling is less than 720 MDA (minimum descent altitude) or visibility is less than 2 miles.

5. Bill Canty does not know where a more detailed break down of runway utilization might be found.

6. Runway 36 is approved for Category II operations with visibility down to 1200 feet RVR. The decision height over the middle marker is 153 feet.

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SUBJECT: Fuel Conservation at the Gate

DATES: 10-15-80 and 10-31-80 Telecons and 11-21-80 visit

PERSONS CONTACTED: Air Transport Association

1. Phil Agee -- 626-4103
2. Roger Fleming -- 626-4014

Notes On Operations

1. The increasing cost of fuel for APU operation is causing airlines to reconsider their use of this power source. Ground Power Units are being used when available and are being installed when practical. Examples of systems in operation and savings include the following:

   a. Eastern Airlines has been saving over 1,000,000 gallons of jet fuel per year since 1977 when 400 Hz Fixed Ground Power systems were installed at Boston-Logan.

   b. Continental Airlines has been saving 1,300,000 gallons of jet fuel per year at Denver, Houston, and El Paso through use of 400 Hz Fixed Ground Power and reduced use of APU's at these airports.

   c. United Airlines has been saving 840,000 gallons of jet fuel per year at their new North Terminal complex at San Francisco International Airport.

   d. Trans World Airlines has recently completed installation of 400 Hz systems at 115 gates at 13 airports.

   e. Piedmont Airlines expects to save 1,000,000 gallons of jet fuel per year at their Atlanta Mid-field Terminal when it becomes operational.

   f. On November 7, 1980, U.S. Air released news that it was planning to install Ground Power for all electrical and heating needs at 23 gates at Greater Pittsburg International airport. They expect to save 22 million gallons of aviation fuel in the first 5 years of use. A unique part of this plan is an agreement with a local utility to provide the needed electrical power. US Air expects their investment to be recovered in approximately 2 years.

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SUBJECT: Meeting on Mobile Lounge Operations at Dulles

DATE: 4 November 1980

PLACE: Dulles International Airport

PERSONS PRESENT:

1. Federal Aviation Administration

    a. Mr. Shirley Poland -- (703) 661-8419
    b. Mr. Roscoe Call -- (703) 661-8407

2. ORI

    a. James K. Thompson

Notes On Operations

1. There are two types of vehicles. FAA refers to the original vehicles as Mobile Lounges and to the newer vehicles as Plane Mates. Plane mates hold more people and can serve the wide body aircraft more economically. Plane mates each make 2 to 3 times more trips per year than the Lounges.

    a. Mobile Lounges seat 72 and hold 102 passengers.

    b. Plane mates seat 102 and hold 150 passengers.

2. Both units use about 2.00 gallons of diesel fuel per trip.

3. Airline operations officers make the equipment decision and may call for either type or for more than one unit depending upon passenger loads and equipment trip costs.

4. The total number of trips made by both vehicles in each of the last 3 years was:

    a. 1979 -- 59,459

    b. 1978 -- 58,460

    c. 1977 -- 57,456

5. The vehicles used 117,472.0 gallons of diesel fuel in 1979 at an average rate of 1.97 gallons per trip.

6. Trip lengths, service times, and the number of trips per flight vary from one airline to another.

7. Airlines pay a service charge for each vehicle trip. This operating charge appears as an additional expense placing the vehicles in an unfavorable perspective when compared to other airports where larger capital investments were made in terminal facilities. Nevertheless, the relatively small amount of fuel used by the Mobile Lounges and Plane Mates presents significant fuel conservation potential at airports where taxi distances are greater.

References

1. US Air News Release dated November 7, 1980.

2. ATA Price List for ATA Reports.

3. November 4, 1980 ATA Fact Sheet.

4. Description:

    a. Design Guidebook 400 Hz Fixed Power System.

    b. Energy Evaluation and Management Manual for Airports.

    c. McCormick-Morgan Power Systems advertisement.

APPENDIX E

OVERVIEW OF AIRCRAFT OPERATING ACTIVITIES AT AIRPORTS

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APPENDIX E

OVERVIEW OF AIRCRAFT OPERATING ACTIVITIES AT AIRPORTS

This section presents an overview of the aircraft operating activities at Washington National (DCA) and Dulles International (IAD) airports. The section is divided into two subsections -- departure activities and arrival activities.

DEPARTURE ACTIVITY SEQUENCE

Figure F.1 shows a generalized departure activity sequence beginning with operations at the gate. Gate operations are terminated after a clearance to pushback is obtained from the tower. It is noted that aircraft can hold at a gate if delays are expected; however, normally aircraft are pushed back from the gate when the pushback clearance is received in order to release the gate for arriving aircraft.

Aircraft are pushed back from gates located in congested areas to areas where engines can be operated without producing a jet blast hazard for nearby personnel, equipment, or aircraft. Pushback distances vary from a few feet to 200 or 300 feet at Washington National. The pushback operation is completed when pushback vehicles are disconnected and the pushback crew gives the all clear signal to the pilot. Aircraft are not pushed back at Dulles International airport because passengers are transported in mobile lounges from passenger gates to the aircraft. Aircraft then taxi from a remote parked position.

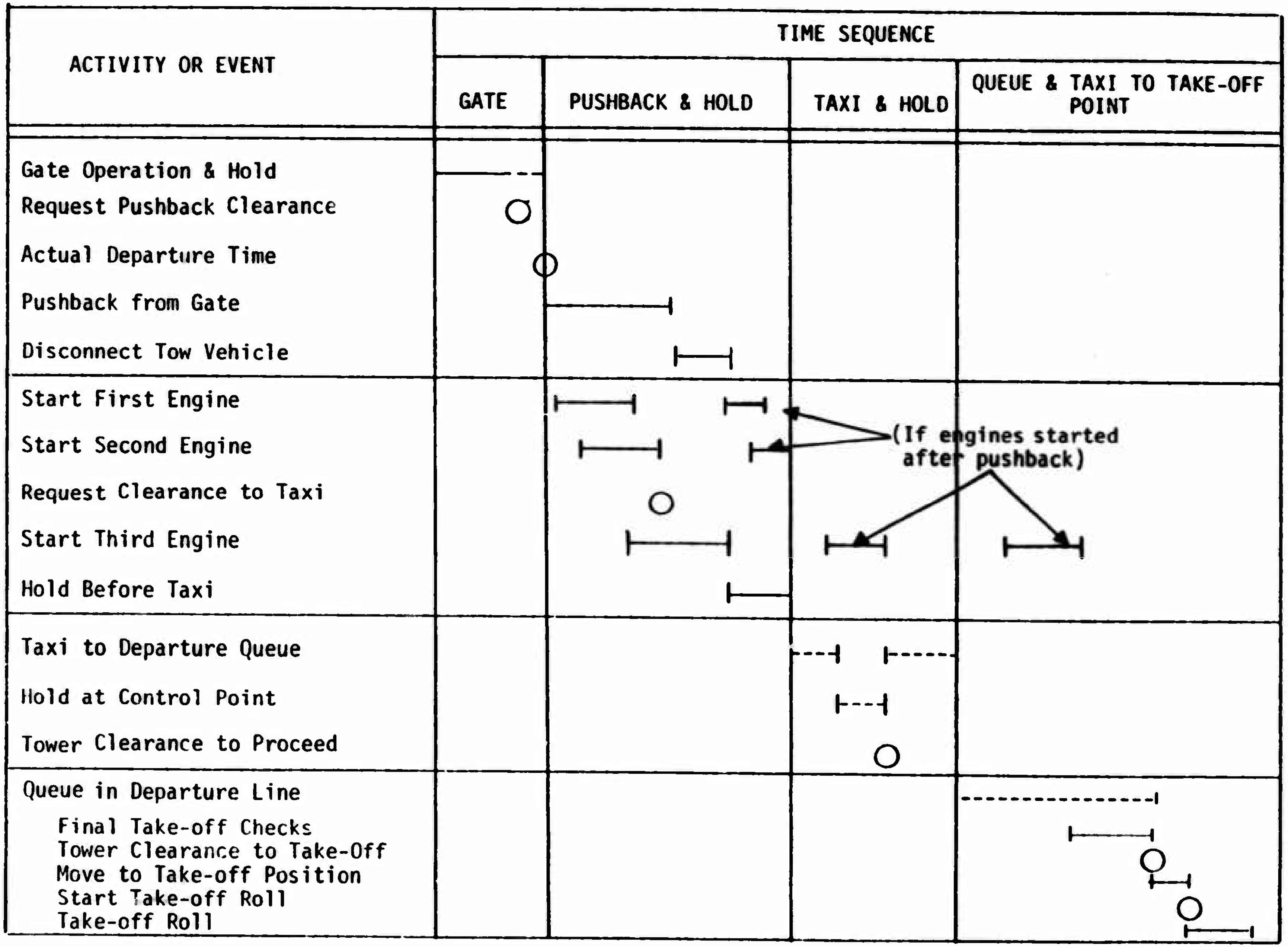

FIGURE E.1. DEPARTURE ACTIVITY EVENT SEQUENCES FOR 3 ENGINE AIRCRAFT

Engines are started at various times as shown in the figure by the dashed lines. They may be started at the gate, during pushback (except for icy conditions) or after the pushback activity is completed. (Engines are sometimes started on APU equipped aircraft before the aircraft is pushed away from the gate because the APU is not performing satisfactorily and an air start unit is needed to start the first engine.)

An engine start cycle can be completed in 30 to 45 seconds. The second engine can be started before the first cycle is completed and is often begun about 30 seconds after the cycle on the preceeding engine was initiated. However, the second start cycle can be commenced within 15 to 20 seconds.

Table F.1 shows operating times for each engine and for all engines for engine start cycles beginning every 30 seconds and completed in 60 seconds. Operating time shown for the first engine started is the time that would elapse before all engines started are ready to taxi. The total amount of operating time on each and on all engines is shown for each completed start cycle.

Tower clearance may be received immediately after requested or delayed as a result of the ground control communications channel being congested or other traffic in the vicinity. In addition, the pilot may delay his departure to avoid a long queue to the departure runway.

Aircraft taxi from the gate or parked positions along designated taxi routes to the departure end of the runway to be used for take-off. They approach along an engine runup area where several aircraft may wait for clearance to take-off. Final pre-flight checks are completed in this area. Runup areas are wide enough in most instances to permit succeeding aircraft to move past an aircraft that is delayed. An airport may have more than one route to taxi to the runway departure point. In addition, takeoffs may be made from more than one point along the longer runways.

Alternate taxiway approaches to the departure point are also sometimes used to route aircraft being delayed for some special airspace problem to a special holding area if it is necessary to free the gate for arriving traffic.

TABLE E.1

OPERATING TIME, MINUTES FOR ENGINE START ACTIVITY

Engine Start Cycle as appropriate for Aircraft	Operating Time on Started Engines, Minutes			
	One Engine Aircraft	Two Engine Aircraft	Three Engine Aircraft	Four Engine Aircraft
First Start	1	1½	2	2½
Second Start	0	1	1½	2
Third Start	0	0	1	1½
Fourth Start	0	0	0	1
Total Engine Operating Time	1	2½	4½	7

The time needed to taxi from the gate to the active runway consists of time to taxi, time associated with holding at control points such as an intersection, and time spent in queues. These lines are shown as dashes on Figure F.1 to indicate that taxi to the active runway is not completed until the entire distance has been traveled.

If the pilot decides to taxi out with less than all engines, the shutdown engine must be started and operating prior to beginning the take-off check activity. It is estimated to take 2 minutes to start the engine and complete the pre-take-off checklist prior to take-off.

The departure activity sequences illustrate the problem faced by pilots when they consider taxi on less than all engines. Their objective is to time the point at which the shutdown engine is started such that it is stabilized and the take-off checklist complete at the time they receive clearance for take-off. The difficulty lies in the uncertainty of whether or for how long they may be delayed before they receive clearance.

ARRIVAL ACTIVITY SEQUENCES

Figure F.2 illustrates the sequence of arrival activities. This activity begins when an aircraft exits from the runway. Engines can be shutdown for less than all engine taxi approximately one and one half minutes after the taxi activity is started. APU's, if needed, are started as the aircraft approaches the gate. Engines are shutdown and gate operations begun when the aircraft stops at the gate position.

Taxi routes for arriving aircraft connect gate locations with a number of runway exits. Runway occupancy times are decreased if exits are made at the first exit at which landing speeds have been reduced enough to permit a safe exit. Since runways must be long enough for an aircraft to be able to stop if a critical flying speed is not obtained during take-off acceleration, the distance needed to stop an airplane is not as long as the runway. Therefore, midfield exits are used for the typical landing.

The time needed to taxi from an active runway to a gate consists of the time needed to taxi towards the gate, the time associated with holding at control points, and any time the aircraft must wait for a gate to be

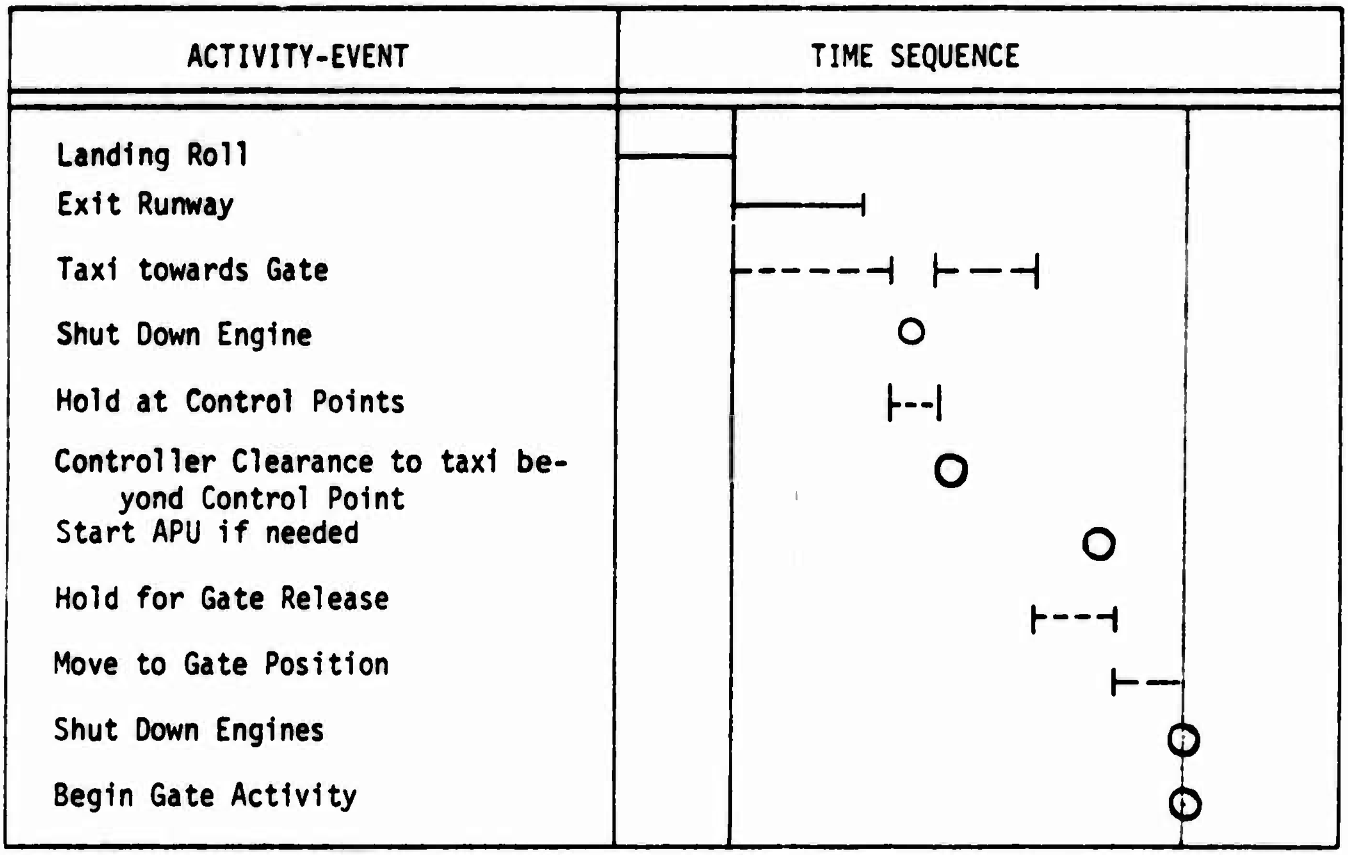

FIGURE E.2. ARRIVAL ACTIVITY EVENT SEQUENCE

released. These times are shown as dashed lines in Figure F.2 to indicate that the taxi activity is not completed until the entire distance has been traveled.

APPENDIX F

SAMPLE FUEL CONSUMPTION ANALYSES

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APPENDIX F

SAMPLE FUEL CONSUMPTION ANALYSES

GENERAL

Estimates of fuel savings were made by considering several individual arrival and departure activity sequences. These examples were used to identify the manner in which fuel was used or saved in particular situations. The examples shown below assume one engine is shut down approximately 1½ minutes after landing. The examples also assume all engines are operating during the final two minutes of each departure.

Definitions for taxi time could cause confusion for those familiar with taxi time data. Airlines include pushback and hold time intervals in data used to estimate fuel reserves needed for aircraft operations on airports. FAA does not use pushback and hold before taxi time intervals for capacity and delay studies. For those studies, taxi time commences when aircraft begin to move under their own power. This study considered the various individual operating activities that constitute aircraft operations on airports. Total taxi time as shown in Appendix A included the holding interval before the aircraft began to move under their own power. Aircraft engines were either operating or being started during this interval and fuel consumption became a significant consideration.

Estimates based upon the data shown in Appendix A were used to develop a tentative estimate of the fuel savings associated with particular airlines and operating practices.

OPERATING ACTIVITY EXAMPLES FOR DCA

Activity Description for Eastern Airlines

Table F.1 is an example of fuel use and conservation for an arrival and departure activity sequence involving an Eastern Airlines B 727-200 aircraft. The arrival was on Runway 18 at 16:11:48 on Friday, November 14, 1980. It was mostly a sunny day with 52^{o}F air temperature. Traffic was heavy and departure delays were occurring. Exit from R18 was on R21. No delays were encountered as the aircraft moved along R21, taxiway "C", and the ramp to Gate 18. Gate 18 is located on the apron near the main terminal. The observed taxi time was three minutes 21 seconds. The average taxi speed for the 3255 foot distance to the gate was 16.2 ft/sec (9.6 knots). The taxi route involved one sharp turn at taxiway "C."

The aircraft remained at the gate for 34 minutes until 16:45:48 when it was pushed back to the traffic line for departure. The time used for pushback was 2 minutes and 27 seconds. The aircraft was disconnected from the pushback vehicle and began to taxi within 35 seconds. It moved along the ramp for 61 seconds before being required to hold at the entrance to taxiway "J." Taxi speed for the 1970 foot taxi distance was 32.3 ft/sec (19.1 knots). It then moved along taxiway "J" during the next two minutes and 39 seconds in what was an extension of the departure queue. After crossing Runway 15, the aircraft moved in the queue for another one minute and forty-five seconds. Total departure taxi time, not including pushback, was 6:00 minutes.

Arrival Estimates. Fuel estimates for the Eastern B 727 aircraft were made assuming fuel flow at 2.55 gallons per minute per engine (7.7 kilograms per minute). The APU fuel flow rate was assumed to be 2 kilograms per minute (40 gallons per hour) for pneumatic as well as electrical loads and 1.3 kilograms per minute (26 gallons per hour) for electrical without pneumatic loads.

TABLE F.1

OPERATING ACTIVITY EXAMPLE DATE: 14 NOVEMBER, 1980

Airport DCA Operation South Airline Eastern Airline

Aircraft B727-200 Idle Fuel Flow per Engine 2.55 G/M 7.7 Kg/m

Temperature $52^{o}F$ mostly sunny APU 2Kg/m or 1.3Kg/m for Electrical Loads only

ACTIVITY	Location or Route	Time or Increment	Fuel Estimates, Kilograms Base	Conservation	Saved
Arrival 16:11:48	R18				
Exit	R21				
Hold	None	100			
Taxi	R21-C-Ramp to G18	+ 3:21			
Total Time		+ 3:21	76.23	64.68	11.55
Distance	3255ft				
Taxi Speed	16.2 ft/sec (9.6 knots)				
Engine Operation			3:21x3 Eng	3:21 x 2 Eng 1:51 x 1 Eng	1:30x1 Eng
Departure 16:45:48	G18 to R18				
Gate	G18	+34:00			
APU		+34:00	68.0	44.2	23.8
Pushback					
Push	G18 to Ramp	+ 2:27			
Hold	Ramp	+ :35	13.47	8.98	4.49
Taxi (movement)	Ramp to "J"	+ 1:01	23.10	15.4	7.7
Hold	Taxi way "J"	+ 2:39	61.21	42.73	18.48
Queue to Final Taxi	"J" to R18	+ 1:45	40.42	40.42	None
Total Taxi	Not including Pushback	+ 6:00	138.20	107.53	30.67
Taxi Distance	1970 to "J"		6:00x3 Eng	4:00 x 2 Eng 2:00 x 1 Eng	4:00x1 Eng
Taxi Speed	19.1 knots 32.3 ft/sec				
TOTAL Engine Operations			214.43	172.21	42.22
TOTAL APU Operations	at Gate Plus Taxi	+34:00 8:27	84.9	61.10	23.8
TOTAL Total Fuel			299.33	233.31	66.02

Fuel used for the arrival base case with no conservation methods used was shown to be 76.23 kilograms. Fuel used for the conservation case assuming one engine was shut down 1½ minutes after landing was shown to be 64.68 kilograms. The conservation strategy saved 11.55 kilograms (3.83 gallons).

Departure Estimates. Eastern pilots start engines to be ready to taxi when released from the pushback vehicle. The fuel used in the engine start cycle was not estimated. Fuel used in the base case was shown to be 138.20 kilograms as compared to 107.53 kilograms for the conservation case. The last engine was probably started before the queue was entered and before crossing runway 15, but the calculations assume only that the engine was running during the 2 minutes before take-off. The conservation for less than all engine operation saved 30.67 kilograms or 10.22 gallons during departure.

The conservation strategy at the gate assumed that the APU was used for electrical power needs only. This seems to be a reasonable assumption because the aircraft was on the ground only 34 minutes and it was a mostly sunny 52^{O}F afternoon. This strategy is assumed to have saved 23.8 kilograms or 7.93 gallons. APU's were assumed to be operating at the full load rate during the entire departure taxi period.

Direct Route Estimate. An arrival earlier in the day at 15:09:48 provided an opportunity to evaluate use of a more direct route for arrival. Table F.2 shows information developed for this example. Traffic was also heavy at that time, and departing aircraft were experiencing delays. The arriving aircraft was able to exit at "F." A 14 second hold was necessary on "F" before the aircraft could taxi on the ramp to Gate 19. Total taxi time including the hold was one minute and 12 seconds. The taxi distance of approximately 800 feet was traversed at speeds of about 13.6 ft/sec (7 knots).

Because of the short taxi times, none of the engines would have been shut down before arriving at the gate and approximately 9.24 gallons of fuel would be used in either the base or conservation case. This compares to 76.23 kilograms for the base case using the longer taxi route and

TABLE F.2

OPERATING ACTIVITY EXAMPLE DATA

Airport DCA Operation South Airline Eastern Airline

Aircraft B727 Idle Fuel Flow per Engine 2.55 G/M 7.7 Kg/m

Temperature 52F Mostly sunny APU 2Kg/m max 1.3 Kg/m for Electrical loads only

ACTIVITY	Location or Route	Time or Increment	Fuel Estimates, Kilograms		
			Base	Conservation	Saved
Arrival 15:09.48	R18				
Exit	F	+ 00:13			
Hold	F and the Ramp	+ 00:14			
Taxi	Ramp to G19	+ 00:45			
Total Time	R18-F-G19	+01:12	27.72	27.72	None
Distance	800ft				
Speed	13.6 mn/sec (7 knots)				
Time	59sec				
Departure 15:07:25	G20-R18				
Gate	G20				
APU					
Pushback					
Push	G20-Ramp	+02:23			
Hold	Ramp near 20	+00:13			
Taxi (movement)	G20-J-A18	1:51			
Hold					
Queue	some where on J to R18	+ 5:22			
Total Taxi		+ 7:26			
Taxi Distance					
Taxi Speed					
TOTAL Engine Operations	At Gate	30:00	200.42	258.59	41.83
TOTAL APU Operations	Plus Taxi	11:01	60.00	39.00	21.00
TOTAL Total Fuel			22.00	42.00	None
			282.42	219.59	62.83

64.68 kilograms for the longer route conservation case. The direct route using exit F reduced fuel use by at least 36.96 kilograms (13.32 gallons) as compared to exit on R21.

Holding At The Gate Estimate. Fuel use comparisons for the 16:45 departure from Gate 18 were made by assuming that the aircraft proceeded from the pushback location to take-off without delay except for the observed 35 second hold before take-off. The distance of 4,460 feet was traversed in three minutes and 44 seconds at an average speed of 20 ft/sec (10.4 knots). Estimates assuming the last engine was started 2 minutes before take-off are as follows:

Activity	Base	Conservation	Saved
a. Engine operation	86.23 kg	72.88 kg	13.35 kg
APU during Taxi	7.46	7.46	None
(Aircraft holds at gate)			
b. From Table E.1 Example			
Engines	138.20 kg	107.53	
APU's	8.27	8.27	
c. Savings (b-a)			
Engines	51.97 kg	34.65 kg	
APU's	0.81	0.18	
	52.78 kg	35.46 kg	

The difference between the "a" and "b" situations is the amount of fuel that could be saved if delays could have been avoided and the aircraft could have held at the gate.

Table F.3 compares fuel savings associated with the various conservation strategies. Starting engines during pushback did not save fuel in either example. The strategy wasted 37.73 kilograms or 12.54 gallons of fuel in the first example and 36.70 kilograms or 12.23 gallons in the second example.

Shutting one engine down 1½ minutes after landing saved 11.55 kilograms or 3.85 gallons in the first example but none in the second example. Starting the last engine 2 minutes before take-off saved 30.67 kilograms or 10.23 gallons in first example and 41.83 kilograms or 13.94 gallons in the second instance.

Using the most direct route for arrival in the second example was found to have saved 36.96 kilograms or 13.32 gallons when compared to the first example with one engine shut down 1½ minutes after landing, and 48.15 kilograms or 16.17 gallons when compared to the base case with all engines operating.

Holding at the gate or at a special location with all engines shut down was shown to save 52.78 kilograms or 17.29 gallons in the first example and 90.2 kilograms or 30.03 gallons in the second example.

The reader is cautioned that annual savings and losses cannot be estimated by multiplying the indicated values by the annual number of arrivals or departures. Delays of the same magnitude did not occur on every flight. When annual savings are calculated, the weighted averages must be considered. Nevertheless, the comparisons do show the relative importance of various fuel conservation strategies when employed in typical operations.

TABLE F.3

FUEL SAVED IN EASTERN AIRLINES
ACTIVITY EXAMPLES INVOLVING A DELAY SITUATION
FOR DEPARTURE FOR SOUTH OPERATIONS

FUEL SAVED				FUEL CONSERVATION OPTION
KILOGRAMS		GALLONS		
EXAMPLE 1	EXAMPLE 2	EXAMPLE 1	EXAMPLE 2	
-37.73	-36.70	-12.54	-12.23	Start engines during pushback
11.55	.00	3.85	.00	Shut one engine down 1½ minutes after landing
30.67	41.83	10.23	13.94	Start last engine 2 minutes before take-off
.00	36.96	.00	13.32	Use most direct route to gate with one engine shutdown 1½ minutes after landing
.00	48.51	.00	16.17	Direct route comparison to base case with no engines shutdown
52.78	90.02	17.29	30.01	Holding at the gate on special location without engines running compared to base case
23.8	21.0	7.93	7.0	Minimizing APU operation at the gate

Activity Description for Trans World Airlines

Trans World Airlines operates from gates located at the south end of DCA terminals. The location is favorable for departure operations to the north and arrival operations to the south. It is unfavorable for departure operations to the south and arrival operations to the north. Table E.4 presents information concerning a south operations example for Friday, November 14, 1980.

The arriving aircraft, a B 727-200, landed on runway 18 at 15:15, exactly. Exit was made on taxiway "F" and the aircraft was permitted to taxi directly to Gate 15 in 1 minute and 54 seconds. It is assumed that one engine was shut down 1½ minutes after landing. This conservation strategy was shown to produce a savings of 3.08 kilograms or 1.03 gallons because one engine would be shut down 24 seconds before arrival at Gate 5.

Another TWA B 727-200 was observed departing from Gate 6 at 15:45:10. The operating activity example for this departure assumed that the departing aircraft was at the gate for 30 minutes. TWA uses a diesel powered GPU when possible for power at the gate. Such a unit would use approximately 7.5 gallons of diesel fuel per hour. It would have used 11.25 kilograms or 3.75 gallons of fuel in a 30 minute period at the gate. Use of the GPU probably saved 48.5 kilograms or 16.2 gallons of fuel.

TWA pilots start engines during pushback. This action was completed in 1 minute and 20 seconds. However, the aircraft was not permitted to taxi immediately and was held for 3 minutes and 31 seconds with engines operating. Starting engines during pushback did not reduce departure time from the gate to take-off. All of the 80.85 kilograms or 26.95 gallons of fuel used for the pre-taxi hold in the base case could have been saved if the pilot could have anticipated delay.

The time to taxi from Gate 6 to the take-off queue was 5.0 minutes. A holding action was not necessary and the aircraft moved through the queue

TABLE F.4

OPERATING ACTIVITY EXAMPLE, DATE: 14 NOVEMBER, 1980

Airport DCA Operation South Airline Trans World Airline

Aircraft B727-200 Idle Fuel Flow per Engine 2.55 G/M 7.7 Kg/m

Temperature $52^{o}F$ mostly sunny APU 2.0 kg or 1.3 kg for electrical loads only

ACTIVITY	Location or Route	Time Interval min:sec	Fuel Estimates, Kilograms		
			Base	Conservation	Saved
Arrival 15:15:00	R18				
Exit	"F"				
Hold	None	100			
Taxi	F to G5	1:54	43.89	40.81	3.08
Total Time		1:54			
Distance	1940 ft				
Taxi Speed	17 ft/sec (10 knots)				
Engine Operation					
Departure 15:45:10					
Gate	G6	30:00			
APU	Used Diesel GPU	30:00	60.00	11.25	48.5
Pushback					
Push	G6 to Ramp	1:20			
Hold	Ramp	3:31	80.85	53.90	26.95
Taxi (movement)	Ramp to R18	5:00	115.50	84.70	30.80
Hold	None	None	0	0	0
Queue & Final Taxi		00:59	23.10	23.10	None
Total Taxi (not including Pushback)		9:30	219.45	161.70	57.75
Taxi Distance	5775 ft				
Taxi Speed	19.3ft sec (11.5 knots)				
TOTAL Engine Operations			263.34	202.51	60.83
TOTAL APU Operations (assumes 40 GPH for Taxi)		40:50	81.66	33.16	48.50
TOTAL Total Fuel			345.00	235.67	109.33

*Diesel GPU at 7.5 gallons per hour = 0.375 Kg/m

in 59 seconds. Starting the last engine 2 minutes before take-off would have saved 57.75 kilograms or 19.25 gallons of fuel.

Table E.4 shows a savings of 109.33 kilograms or 36.44 gallons of fuel for the TWA arrival and departure activity example. Starting engines during pushback resulted in a net loss involving 80.85 kilograms or 26.95 gallons for the base case and 53.96 kilograms or 17.97 gallons for the conservation case. Not starting one engine saved 26.95 kilograms or 8.95 gallons of the 53.90 kilograms or 17.97 extra gallons used because two engines were ready to taxi too soon. All of the 80.85 kilograms or 17.97 gallons could have been saved if engine start could have been delayed until permission to taxi was assured.

The direct route conservation option for TWA arrivals to the south is of little practical consequence except that exit on R21 requires a sharp turn which would reduce taxi speed. Exit on taxiways "A" and "C" results in possible delay at the intersections with R21.

OPERATING ACTIVITY EXAMPLE FOR IAD

Trans World Airlines uses Gates 5, 6, 7, and 8. Ground power is available at Gates 7 and 8. In this example, a TWA L 1011 aircraft landed at 14:35:35 on Friday, November 7, 1980. The landing was on 19R. The third high speed exit, described as exit 2, was used. Taxi time from the runway to the gate was 6 minutes and 55 seconds. A savings of 56.9 kilograms or 18.9 gallons of fuel was saved because an engine was shut down 1½ minutes after landing. This compares to a fuel use of 218.3 kilograms or 72.4 gallons if the engine was not shut down.

Taxi distance was 5,200 feet, approximately, with one 90° turn. Assuming a parking time of 30 seconds, the distance was travelled in 6 minutes and 25 seconds at an average speed of 16 ft/sec or 9.5 knots.

The L 1011 remained on the ground for one hour and 5 minutes. It was assumed that APU's were shut down and that ground power was used while the aircraft was on the ground. The APU selector control would have been set on the minimum mode if GPU's or fixed ground power were not used. Not

using the APU for one hour saved 50 gallons or 250 kilograms of fuel according to the U.S. DOE 1975 Report "Examination of Commercial Aviation Operational Energy Conservation Strategies." Higher fuel burn rates are indicated by other references and savings could be greater.

The TWA L 1011 departure was on runway 19L at 5:40:30 p.m. The aircraft was not required to hold or queue and departure taxi was in four minutes and forty seconds. All engines were started and a most direct route to the runway was used.

Table F.5 shows operating activity examples for B 727 aircraft. The examples were constructed from observations involving aircraft using Gates 18-20. Taxi times were calculated in terms of distance and speed assumptions and found to compare with observed data. A taxi speed of 25 ft/sec, 15 knots approximately, was assumed for 01R and 19R arrivals. A higher speed of 20 knots or 33.78 ft/sec was assumed for the 30L operations for which there were no observations. Estimated taxi distances vary from 400 ft for 19R and 520 ft for 01R to 4,250 feet for 30L.

Taxi times were estimated to be 3 minutes and 58 seconds for 19R arrivals moving to the Gate 18 to 20 area. These averages are roughly comparable to those observed at Dulles.

Estimates of fuel savings resulting from shutting down one engine 1½ minutes after arrival were shown to vary from 12.8 kilograms for 19R and 19.2 kilograms for 01R arrivals to 46.2 kilograms for 30L arrivals.

Taxi distances for departures on 19L at Dulles vary from 4,200 feet to 8,500 feet for aircraft parked at odd numbered gates located on the terminal side of the parking line. Distances for aircraft arriving on 19R are shorter but the most favored location shifts from the east side to the west side. Aircraft parked on the south side at even numbered gates must travel 500 to 1,000 feet farther in either instance if they follow the clockwise taxi direction rule and use one of the passages between the two parking lines.

TABLE F.5

B-727 ARRIVAL DULLES

	COMPUTATION FOR GATES 18 TO 20 EXAMPLES		
Runway	01R	19R	30L
Exit	#4	#2	#2
Taxi Route	#4-G20	#2-G20	#2-Taxiway-G20
Taxi Distance	5200 ft.	4000 ft.	14,250 ft.
Taxi Speed	25 ft/sec	25 ft/sec	33.78 ft/sec
Taxi Time	208 sec	160 sec	422 sec
Park Time	30 sec	30 sec	30 sec
Hold Time	--	--	--
Total Time	238 sec	190 sec	452 sec
(Min:Sec)	3:58	3:10	7:32
Observed Averages			
Braniff	3:04	3:41	None
Continental	3:53	2:58	None
Fuel Used			
Base Case	92.4 kg	73.1 kg	173.2 kg
Conservation	73.2 kg	60.3 kg	127.0 kg
Fuel Saved	19.2 kg	12.8 kg	46.2 kg

Permitting aircraft using the south, even numbered gates to use the most direct taxi route eliminates the extra distance but does not eliminate the need to make a 180 degree turn. At least part of the distance avoided by the direct route option is travelled at a slow 10 to 15 feet per second taxi speed and the taxi time saved is about 60 seconds.

Taxi distances are reversed for north operations and the direct route taxi option saves about 60 seconds for aircraft parked at odd numbered gates on the terminal side of the parking lines. The B 747's are a possible exception. These aircraft sometimes taxi the entire length of the parking lines and return if vehicles are in the passages. For example, a B 747 parked at Gate 26 or 28 might taxi 4,000 feet to the east side of the line and back on the south side for a departure on 01L. The total distance to the taxiway for 01L would be 9,000 feet when the direct route for taxi cannot be used and when taxi through the passages cannot be permitted. In typical circumstances the times are increased by about 1 minute for unfavorable locations.

The estimated 60 second direct route taxi time savings applies to half the arriving and departing aircraft. It is convenient to assume that the average arriving and departing aircraft save 30 seconds by using the direct route taxi option. The direct route savings for IAD is estimated to be as follows:

Taxi Out	173,317 kilograms
Taxi In	137,098 kilograms
TOTAL	310,415 kilograms

APPENDIX G

QUANTIFICATION OF CURRENT FUEL CONSERVATION PRACTICES AND PROCEDURES

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APPENDIX G

QUANTIFICATION OF CURRENT FUEL CONSERVATION PRACTICES AND PROCEDURES

Estimates of fuel savings through the implementation of the practices and procedures described in Section IV were quantified using the operations, fleet mix, and fuel flow rate data described in Section II. Actual fuel savings were based upon the airline practices and the data collected during the on-site investigations conducted at DCA and IAD. Examples of the analysis conducted using this data are contained in Appendix E.

Potential fuel savings were determined by maximizing implementation of the practices and procedures by all the airlines.

STARTING ENGINES DURING PUSHBACK

Braniff, Eastern, Trans World, United and U.S. Air start engines during pushback from the gate at DCA. American and Delta Airlines start engines after pushback. Engine start during pushback is intended to reduce the time needed to move the aircraft from the gate to take-off. This action would save fuel and reduce emissions associated with APU operation if time from the gate is actually reduced. Table G.1 illustrates the effect of engine start procedures on the length of time aircraft were required to hold before taxi for the B 727 aircraft operating at DCA. The cumulative frequencies show the number of instances when the hold before taxi time intervals were equal or greater than the indicated intervals.

TABLE G.1

EFFECT OF ENGINE START PROCEDURE ON HOLD BEFORE TAXI

HOLD BEFORE TAXI ELAPSED TIME INTERVALS, MINUTES:SECONDS	CUMULATIVE FREQUENCY OF OCCURENCE			
	START ENGINES AFTER PUSHBACK		START ENGINES DURING PUSHBACK	
00:00 - 00:14	32 Cases*	100%	97 Cases*	100%
00:15 - 00:29	32	100	93	96
00:30 - 00:44	30	94	89	82
00:45 - 00:59	26	81	60	62
01:00 - 01:14	18	56	42	43
01:15 - 01:29	14	44	27	28
01:30 - 01:44	8	25	18	18
01:45 - 01:59	6	19	17	17
02:00 - 02:29	4	12	12	12
02:30 - 02:59	3	9	10	10
03:00 - Max.	3	9	6	6

*These columns give the cumulative frequency of cases for wh n elapsed times were equal or greater than indicated intervals.

Engine start during pushback appears to enable B 727 aircraft to begin to taxi approximately 15 seconds sooner than if the engines were started after pushback. A larger difference of at least 45 seconds was expected; however, the comparisons are fairly consistent for each time arrival. For example, the delay after pushback exceeded 45 seconds for 81% of the 32 instances associated with airlines that typically start engines after pushback. This compares to delays exceeding 30 seconds for 82% of the 97 instances associated with airlines that typically start engines during pushback. Similar comparisons can be made for other delay intervals.

Delays after pushback exceeded 1 minute for 43 percent of the instances when engines were started during pushback and 56 percent of the instances when engines were started after pushback. Delays exceeded two minutes approximately 12% of the time in either instance. It is clear that some unplanned factor other than readiness to taxi was affecting the delay before taxi.

Several factors could account for the discrepancy in data. First, pilots who stated that they start their engines during pushback may have waited until after pushback was complete. Conversely, pilots who stated that they start their engines after pushback may have started their engines earlier. This would have skewed the data and resulted in less differential between the ready to taxi times. Third, time to unhook from the pushback vehicle was considered part of the pushback procedure. This time interval (30 seconds on the average) could have been used for either procedure or both. Finally, either airline could request clearance to taxi as soon as the pushback vehicle was clear of the aircraft (whether or not the engines were running and stabilized and hence ready to taxi).

If one were to use the on-site collected data, the practice of starting engines during pushback would appear to be counter productive as a fuel conservation practice since it would permit aircraft to commence to taxi only 15 seconds sooner than those that start engines after pushback. A 15 second reduction in APU operating time and fuel burned is more than offset by the fact that engines would be operating one or more minutes before taxi was commenced.

In view of this apparent conflict, the computations were considered unreliable and are not reported -- either by airline or in aggregate.

As stated above, there is a potential for fuel savings provided the pilots time their engine start procedures such that all engines are running at the time the pushback vehicle is disconnected from the aircraft. The savings would amount to the fuel saved by shutting the APU down sooner than they would if they had waited until they had completed the pushback activity before starting their engines. The potential fuel savings shown in Table G.2 are based upon the following assumptions:

- The pilot was able to time starting his engines such that they were running and stabilized (ready to taxi) at the moment the pushback vehicle was disconnected and clear of the aircraft.
- Delay after ready to taxi and aircraft movement would be the same for either practice.
- APU's would be shutdown immediately after the engines were started and stabilized.

The "start engines during pushback strategy" is not applicable to operations at Dulles.

TAXIING OUT OR IN WITH ONE OR MORE ENGINES SHUTDOWN

With the exception of the GE CF6 series of engines (which have a very low idle power setting) aircraft operating at DCA and IAD are capable of taxiing at maximum gross weight with all engines at idle. As the gross weight becomes less (with less payload or fuel) the pilot compensates for the added thrust by the use of brakes.

When the pilot uses less than all engines for taxi, it would be expected that he would be required to compensate for the lost thrust by adding power on the remaining engines. This is true for many operations at IAD where the aircraft carry full fuel loads and hence have high take-off gross weights.

TABLE G.2

POTENTIAL FUEL SAVINGS
STARTING ENGINES DURING PUSHBACK DCA

AIRLINE	FUEL SAVINGS (KG)	COST (79$)
Air Florida	1,599	288
American	39,231	7,062
Braniff	16,815	3,027
Delta	25,150	4,527
Eastern	104,721	18,850
National	22,145	3,986
N. Central	38	7
Northwest	43,648	7,857
Piedmont	27,951	5,031
Republic	1,088	196
Trans World	28,399	5,112
United	30,548	5,499
U.S. Air	38,273	6,889
Western	1,409	254
TOTAL	381,015	68,583

However, at DCA, where the average stage length is approximately 400 nmi, the aircraft are able to taxi on less than all engines at idle power. This fact has been verified by conversations with the airlines regarding the take-off gross weights of departing aircraft. Some of the power available versus power required calculations were marginal and as such, it is conceivable that in some instances, the pilots may be required to taxi at a higher power setting than idle when taxiing on less than all engines. In-addition, since most fuel has been consumed before landing, additional power would not be required to taxi in on less than all engines.

Tables G.3 and G.4 present estimates of the actual and potential fuel savings that could be achieved at DCA and IAD airports by taxiing in or out on less than all engines. The fuel savings are the difference between fuel consumed in the baseline estimate and the fuel which would be consumed if aircraft taxied in or out on less than all engines. The algorithm used for these calculations is as follows:

NO. OPS x FFR x TIM x % = FC

Where NO. OPS = number of operations by airline by type of aircraft

FFR = Fuel Flow rate for the power setting required based upon the average take-off gross weight by airline and type aircraft. This data was obtained from conversations with the airlines operators.

TIM = Time in mode adjusted by the time required to start-up or shut down an engine.

% = Percent that a particular airline uses this procedure for taxi out or taxi in.

FC = Fuel consumed.

Potential fuel savings were derived by assuming all airlines use the procedures one hundred percent of the time.

TABLE G.3

POTENTIAL AND ACTUAL ANNUAL FUEL SAVINGS
DUE TO TAXIING ON LESS THAN ALL ENGINES
AT DCA
(Based on 1979 Data)

AIRLINE	AIRCRAFT TYPE	ACTUAL SAVINGS PER YEAR (kg)		POTENTIAL SAVINGS PER YEAR (kg)	
		OUT	IN	OUT	IN
QH	B 737	0	0	13,407	2,439
	DC 9	420	1,290	4,201	1,290
AA	B 727	39,207	117,691	392,062	117,691
BN	B 727	18,567	26,923	185,678	26,923
DL	B 727	25,441	49,195	254,410	49,195
	DC 9	921	1,707	5,007	1,707
EA	B 727	194,812	89,384	389,624	119,179
	DC 9	70,432	157,624	704,320	157,624
NA	B 727	15,895	52,983	158,949	52,983
NW	B 727	19,566	121,854	195,660	121,854
PI	B 727	7,504	34,128	75,040	34,128
RC	DC 9				
TW	B 727	32,303	98,623	323,034	98,623
UA	B 727	26,941	25,947	269,417	25,947
	B 737	0	0	133,249	70,934
AL	B 727	1,423	5,790	14,230	5,760
	DC 9	9,469	50,349	85,232	50,350
	BAC 111	4,787		47,870	
WA	B 727	758	8,641	7,577	8,641

TABLE G.4

POTENTIAL AND ACTUAL ANNUAL FUEL SAVINGS
DUE TO TAXIING ON LESS THAN ALL ENGINES AT IAD
(BASED ON 1979 DATA)

AIRLINE	AIRCRAFT TYPE	ACTUAL SAVINGS (kg)		POTENTIAL SAVINGS (kg)	
		OUT	IN	OUT	IN
AA	B 727	1,974	15,413	19,749	15,413
	B 707	0	46,455	120,847	46,455
	B 747	0	106	87	106
	DC 10-10	0	39,124	10,291	39,124
BN	B 727	8,504	42,211	85,037	42,211
	DC 8	0	13,106	8,895	13,106
	SSC	0	56,690	46,810	56,690
CO	B 727	3,431	22,269	34,314	22,269
DL	B 727	741	5,780	7,406	5,780
	DC 8	0	220	176	220
	DC 9	777	5,630	7,767	5,630
	L 1011	0	34	35	34
EA	B 727	5,189	38,146	51,887	38,146
	DC 9	1,096	7,942	10,959	7,942
	L 1011	0	34	35	34
NW	B 727	47	343	466	343
	B 747	0	37,054	30,558	37,054
	DC 10-40	0	22,277	29,568	22,227
OZ	DC 9	1,681	11,333	14,007	11,333
PA	B 707	0	12,580	32,725	12,580
	B 747	0	116,041	58,227	116,041
PI	B 727	9	64	87	64
	B 737	0	0	616	578
RC	DC 9	2,957	23,762	26,534	23,762
TW	B 727	379	2,782	3,786	2,782

TABLE G.4 (Continued)

AIRLINE	AIRCRAFT TYPE	ACTUAL SAVINGS (kg)		POTENTIAL SAVINGS (kg)	
		OUT	IN	OUT	IN
TW	B 707	0	47,281	122,994	47,281
	B 747	0	424	348	424
	DC 9	6	43	59	43
	L 1011	0	22,788	23,759	22,788
UA	B 727	963	4,233	9,626	4,233
	B 737	0	0	8,441	3,509
	B 747	0	212	174	212
	DC 8	0	90,717	72,182	90,717
	DC 10	0	10,390	23,600	10,390
BA	B 747	0	26,033	21,853	26,033
	SSC	0	38,284	31,612	38,284
AF	SSC	0	51,045	42,149	51,045

PLANNING LANDING ROLL TURN-OFF AND TAXIING TO THE TERMINAL WITH THE MOST DIRECT ROUTING

Runway exit choice was evaluated by comparing the exits used by three airlines located at the south end of the field at Washington National Airport as shown in Figure G.1 (American, Northwest, and Trans World Airlines) with exits used by three airlines located at the North terminal (Braniff, Delta, and Piedmont Airlines). The comparisons are shown in Table G.5. Data samples examined did not indicate a significant difference. For north operations on runway 36, all of the airlines used taxiway "I" most of the time and very few aircraft used taxiway "H" (See Figure G.1), which would be nearest to airlines located at the south end of the field. Taxiway "J" located at the North end of the field was the second most used exit by both airline groups.

Taxiway exits "F" and "E" were used most often by all of the airlines for South operations. All six airlines made exits on taxiway "A" located at the south end of the field.

Taxiways "A" and "J" have runway crossing control points and would be expected to produce control delays as well as extra time to taxi the greater distances.

If one considers that a landing roll that extends 2000 feet beyond the preferred exit and assumes that the additional distance on the runway resulted because the aircraft was traveling too fast to make the preferred exit turn safely, the 2000 feet could be traveled in approximately 35 seconds. Braking and reverse thrust forces would be reduced, and the fuel used to reach the more distant exit might not be very different from that which would have been used to make a nearly panic slow down for the turn.

The time required to taxi 2000 extra feet back towards the gates would be 100 seconds at 20 ft/sec (13.6 MPH) or 200 seconds at 10 ft/sec (6.8 MPH). Taxiway exits "A" and "J" are about 2000 feet beyond the preferred exits and each involves a runway crossing control point that could cause delays. (The faster taxi speeds (13.6 ft/sec) would probably be used at these locations if delays are not expected at intersecting runway control points.) Two to four minutes additional taxi time and a corresponding amount

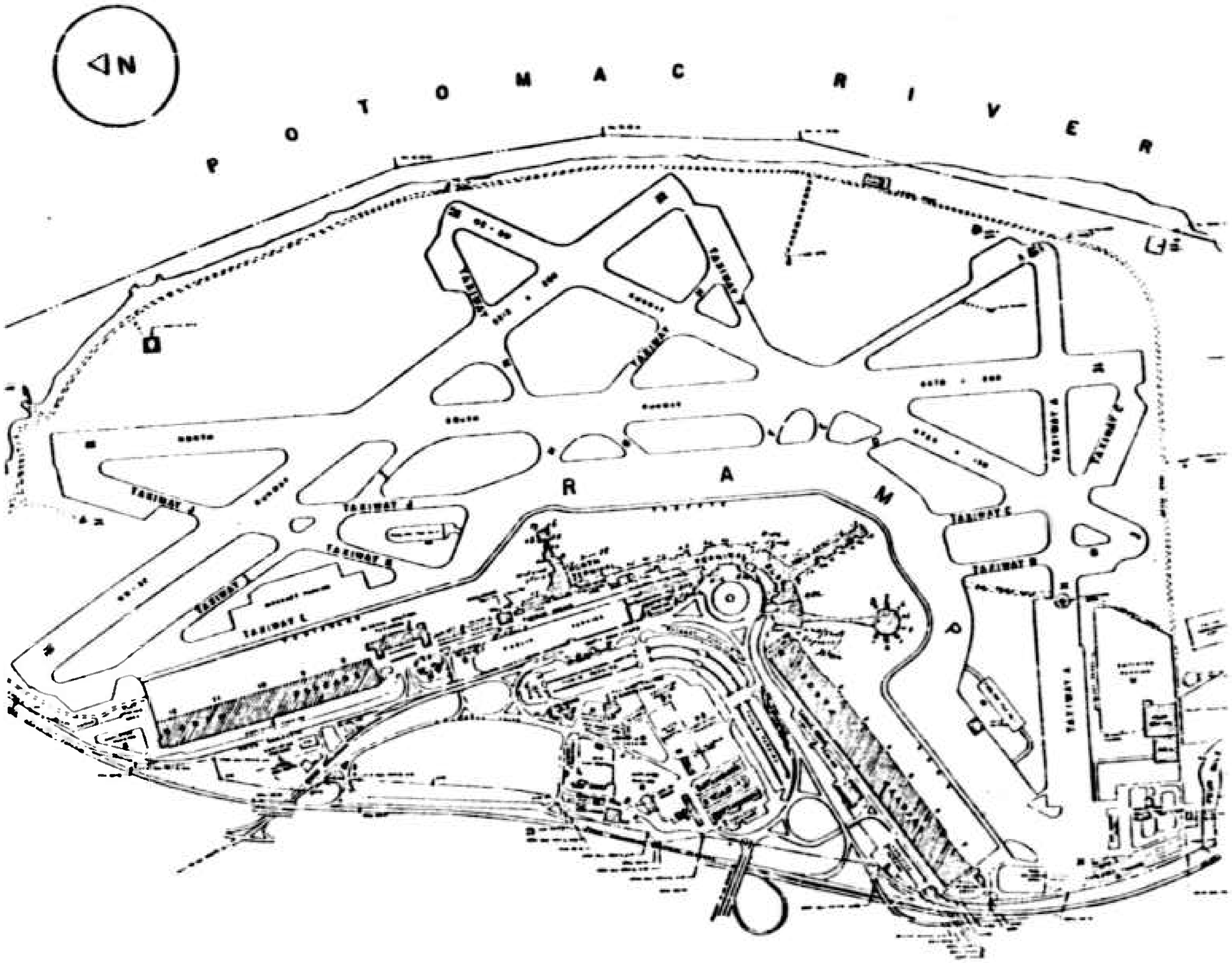

FIGURE G.1. WASHINGTON NATIONAL AIRPORT

TABLE G.5

DCA RUNWAY EXIT CHOICE COMPARISONS

	AIRLINE	TAXIWAY USED FOR EXIT								
		J	I	H	G	F	E	D	C	A
SOUTH OPERATION	American					1	3	1	3	1
	Northwest					1	3	1		2
	Trans World					2	1	1		1
	TOTAL					4	7	3	3	4
	Braniff					3	1		1	1
	Delta					1	4	1		2
	Piedmont			1	4	9	4		1	1
	TOTAL			1	4	13	9	1	1	4
NORTH OPERATION	American		6	1						
	Northwest	1	2							
	Trans World	3								
	TOTAL	4	8	1						
	Braniff	1	3							
	Delta	1	6							
	Piedmont	2	4	1						
	TOTAL	4	13	1						

of fuel would be used each time the preferred exit is not used at Washington National Airport.

An estimate of fuel loss due to a 10% usage of the "A" and "J" taxiways by commercial jet aircraft was made for DCA (see Table G.6). It was assumed that 2 minutes of additional taxi time resulted from the use of these taxiways. It was also assumed that the operators shut down one engine for all aircraft except the B 737, and that the engines were at idle for all aircraft. The total annual fuel loss due to indirect routing, given these assumptions, would be 250,231 kg (109,202 gallons) at DCA. In many cases, most direct routing is not possible because of ground traffic conditions. The use of additional reverse thrusting in order to shorten the taxi route would tend to offset the fuel savings achieved through the use of direct routing. The real potential fuel savings which would be accrued through the use of more direct routing at DCA are therefore somewhat less than this estimate.

The airport layout for Dulles International Airport is shown in Figure G.2. Distances from runways to gates are large compared to distances at Washington National Airport. Therefore, the need to exercise direct route taxi options to conserve fuel is greater at Dulles since taxi distances are greater. Fortunately, the freedom to exercise direct route options is also greater because of the lack of heavy traffic. Aircraft were permitted to land on either runway and to use the shortest taxi route during the data collection period.

The commercial air carriers tended to use the 19R-01L runway in order to avoid the general aviation traffic on the 19L-01R runway. For departing commercial aircraft, the left runways were generally preferred over the right runways because the end of the runway is closer to the apron for left than for right runways. During South operations, the 19R runway was sometimes used by departing air carriers because of heavy traffic on 19L. No departures were observed on the 01R runway.

Inbound commercial aircraft generally exited near the middle of the runway, so there was no substantial difference between taxi distances for right runway operations and taxi distances for left runway operations.

TABLE G.6

FUEL LOSS DUE TO A 10% USAGE OF TAXIWAYS
"A" OR "J" BY COMMERCIAL JET AIRCRAFT AT DCA

Aircraft Type	Kg Used
B 727	173,758
BAC-111	7,021
DC 9	39,490
B 737	29,962
TOTAL	250,231

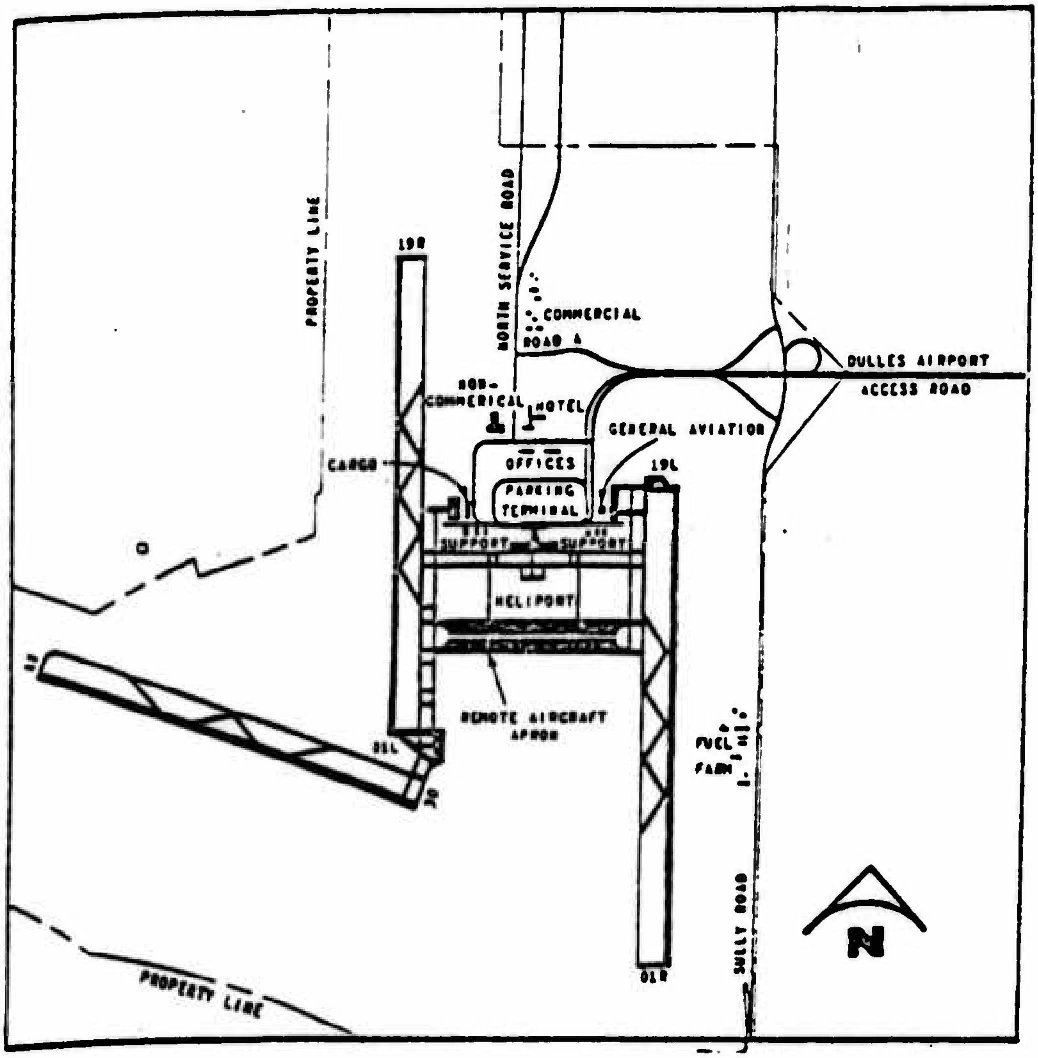

FIGURE G.2. DULLES INTERNATIONAL AIRPORT

Left runway arrivals must make a sharper turn than right runway arrivals, but this factor seemed to have no effect on runway use preferences at IAD. The major factor affecting runway preference for inbound aircraft was the heavy GA traffic on the 19R-01L runway.

In most every case, the air carriers chose to use the runway which made possible the use of the most efficient taxi route between the runway and the apron. It was not clear, however, that the inbound air carriers always adequately considered their ultimate destination on the apron. Outbound air carriers appeared to consider this factor more closely. Substantial fuel savings would result from reducing taxiing on the apron at IAD. These savings could be achieved through more careful consideration of apron position when choosing which runway to use. Additional savings would result from allowing air carriers to taxi in a counterclockwise direction on the apron in cases in which the use of the procedure would shorten taxi distances. Controllers at Dulles often allow this practice upon request of the pilot, but the practice is not utilized as often as it should be. The low volume of traffic at Dulles and the large size of the taxiways would allow the use of two-way traffic on the apron almost all of the time without compromising safety. The amount of fuel which could be saved through more careful runway choice and the enhanced use of two-way traffic at IAD can scarcely be quantified, but given the large taxi distances required at IAD and the size of the aircraft, a small percentage reduction in taxi times at Dulles would save very large quantities of fuel. The scale of these potential savings is presented in Table G.7, which shows how much fuel is consumed during one minute of inbound taxiing by each of the major aircraft types at IAD.

Smaller savings could be achieved by general aviation aircraft at IAD. The 19L-01R runway is generally most efficient for and generally used by GA operators at Dulles. The runway length necessary to land and brake many GA aircraft is far shorter than the distance between the end of 19L and exit 6 and the distance between the end of 01R and exit 2. Ground taxi times could be substantially reduced for many GA aircraft if there were an exit halfway between the end of 19L and exit 6, and if mid-field landings were

TABLE G.7

FUEL CONSUMED BY LARGE AIRCRAFT AT
IAD DURING ONE MINUTE OF INBOUND TAXIING

AIRCRAFT TYPE	ENGINE TYPE	FUEL CONSUMED DURING ONE MINUTE OF INBOUND TAXIING (kg)	
		All Engines	Less than all Engines
SSC	Olympus 593	101	51
B 747	JT9D	51	25
DC 10	CF6	23	19
	JT9D	38	25
L 1011	RB211	31	21
B 707	JT3D	27	14
DC 8	JT3D	27	16
B 727	JT8D	23	15
DC 9	JT8D	15	8
B 737	JT8D	15	--

allowed on 01R. Similar savings could be made by allowing mid-field take-offs for small GA aircraft using 01R. Shortening the time that GA aircraft spend taxiing on the runway would save fuel indirectly by reducing the time that departing aircraft must wait to use 19L, and by making 19L and 01R more available to incoming aircraft. The construction of an additional runway exit and the judicious granting of mid-field take-off and landing clearances to small aircraft should not cause any safety problems. The indirect fuel savings resulting from reduced air carrier hold times at 19L would be substantial, however.

GATE HOLD PROCEDURES

Fuel savings are being realized by the airlines by holding their aircraft at the origin airports when there are anticipated air traffic delays at the destination. Based upon the length of the anticipated delays, aircraft will either remain at the gate on ground power units (GPUs) or move to a holding area where they shutdown their engines and operate on the aircraft's auxiliary power units (APUs). Savings, of course, are based upon the length of delay and consist of the differences in fuel consumed at cruise in a holding pattern versus that consumed on the ground. These savings are shown in Table G.8 by aircraft type for each minute the aircraft is able to avoid holding. These savings are based upon the power source used on the ground (engines at idle, APUs, or GPUs). It is noted that there are no fixed power facilities at either DCA or IAD.

FUEL LOAD PLANNING PRACTICES

Fuel load planning practices have an insignificant impact on fuel conservation at DCA and IAD airports since the aircraft have ample power at idle to carry the extra fuel weight when taxiing with all engines running.

However, at DCA, when the practice of tankering is added to the taxi on less than all engine procedure, the additional fuel weight could raise the power required above the marginal power available at the idle power setting. This would require the pilot to add additional thrust to

TABLE G.8

CONSUMPTION RATES (KG/MIN)

AIRCRAFT TYPE	ENGINES CRUISE POWER	ENGINES IDLE POWER	ENGINES OFF APU POWER	ENGINES OFF GPU POWER
B 747	405	50.7	2.4	0.08
DC 10	260	33.8	1.0	0.08
L 1011	277	39.6	1.0	0.08
B 707	242	27.2	N/A	0.08
DC 8	242	27.2	N/A	0.08
B 727	152	23.1	0.7	0.08
B 737	120	17.3	0.7	0.08
DC 9	101	15.4	0.7	0.08
BAC 111	87	13.4	0.7	0.08
YS 11	19	6.2	0.3	0.08

the engines. Assuming that each aircraft was at marginal power, the additional fuel required to carry each additional 1,000 kg of fuel is shown in Table G.9.

Tankering in conjunction with less than all engine taxi is not considered a separate problem at IAD since aircraft generally take-off with a full fuel load and the additional power required on the remaining engines was reported in the less than all engine taxi procedure computations.

TABLE G.9

ADDITIONAL FUEL CONSUMED BY TAXIING ONE MINUTE WITH 1000 kg ADDITIONAL FUEL AT DCA

AIR-CRAFT TYPE	# OF ENGINES OPERATING	THRUST/ENGINE AT IDLE (kg.t.)	MAXIMUM GROSS WT. ALLOWABLE FOR TAXI WITH ENGINES AT IDLE (kg)	MAXIMUM GROSS TAKE-OFF WT. (kg)	ADDITIONAL FUEL CONSUMED FOR EACH 1000 kg WT. ABOVE WT. IN COLUMN 4 (kg/min)
B 727 100, 200	3	395	79,000	64,410 - 78,015	N/A
	2	395	52,667	64,410 - 78,015	.052
DC 9 10, 30, 50	2	395	52,667	35,245 - 51,710	N/A
	1	395	26,333	35,245 - 51,710	.053
B 737 200	2	395	52,667	26,868	N/A

APPENDIX H

IMPACT OF EXISTING PRACTICES AND PROCEDURES ON SOCIAL/ECONOMIC CONSIDERATIONS

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APPENDIX H

IMPACT OF EXISTING PRACTICES AND PROCEDURES ON SOCIAL/ECONOMIC CONSIDERATIONS

Each of the fuel conservation practices and procedures currently implemented at DCA and IAD airports were assessed to determine the possible effects of implementation on:

- Safety
- Airport capacity
- Passenger convenience
- Noise and Air Quality levels
- Airline/Airport Revenues.

When possible, these social/economic considerations were quantified. In other instances, the evaluation was, by the nature of the consideration, purely subjective. Each of the considerations are discussed below and summarized in Table H.1.

SAFETY IMPACT CONSIDERATIONS

The impact of fuel conservation practices and procedures on safety were examined initially by an ORI project team consisting of pilots, engineers, and operations personnel. This team examined each of the practices and procedures currently implemented by the airlines as they would impact on safety. From this analysis, a list of potential problem areas was developed

TABLE H.1

SUMMARY OF CONSERVATION IMPACTS

CONSERVATION STRATEGY	SAFETY		NOISE		EMISSIONS		AIRPORT CAPACITY		AIRLINE COST REVENUES		PASSENGER CONVENIENCE	
	DCA	IAD	DCA	IAD	DCA	IAD	DCA	IAD	DCA	IAD	DCA	IAD
Start Engines During Pushback*												
Potential	0		0		+		0		+		0	
Actual	0		0		-		0		-		0	
Taxi Using Less Than All Engines*												
Taxi In (Arrival)	0	0	+	+	+	+	0	0	+	+	0	0
Taxi Out (Departure)	0	0	+	+	+	+	0	0	+	+	0	0
Use Direct Route												
Taxi In	0	0	+	+	+	+	-		+	+	0	0
Taxi Out	0	0	+	+	+	+	0	0	+	+	0	0
Hold for Departure Delay												
At Gate	0	0	+	+	+	+	0	0	+	+	+	+
At Special Location	0	N/A	+	N/A	+	N/A	0	N/A	+	N/A	0	N/A
Minimize APU Use At Gates	0	0	+	+	+	+	0	0	+	+	0	0
Fuel Load Planning	0	0	0	0	0	0	0	0	0	0	0	0

+ = Beneficial Effect
- = Potential Deleterious Effect
0 = Neutral Net Effect or Not Perceptible

* = Needs Study on Demonstration
N/A = Not Applicable

which were then explored during the on-site visits and telephone conversations with the airline and tower operations personnel.

From these investigations the following conclusions were derived:

- Except when runway surfaces are icy, engine start during pushback has no significant effect on operating safety.
- Taxi with less than all engines operating poses a potential safety problem when thrust is increased to unstick and accelerate to taxi speeds. In congested areas, the safety problem results because of jet blast problems when more thrust is added to operating engines. This safety problem is more acute when aircraft come to rest at low spots and when aircraft are departing at heavy gross weights. RPM limits are established for each aircraft and all engines must be used when the limits might otherwise be exceeded in congested areas. Therefore, the potential safety problem is controlled as needed through use of operating procedures.
- Starting an engine during taxi or in the engine run-up area is not a significant problem for air carrier aircraft. These aircraft have internal fire protection systems that would be used to control or suppress an engine fire. Engine run-up and taxiways where engines are started for the less than all engine taxi option for departure are as accessible to airport fire protection vehicles as engine start areas at or near gates. The height of aircraft engines above the ground make use of protection equipment at aircraft gates impractical. Starting air carrier engines in engine run-up areas or along taxiways does not introduce a new fire safety problem.
- Runway exits at locations providing the most direct geographic route to the gate can be used safely when touch down location and aircraft speed can be controlled sufficiently to permit use of the exit. This option is more difficult to exercise when runways are short. Extending a touch down point and landing roll are generally easier to accomplish than landing to insure use of a midfield exit. The option does not

affect safety because pilots do not compromise safety to effect turn-off at a midfield exit.

- Gate hold procedures have no practical affect on aircraft safety.
- Tankering actions would not affect aircraft operating safety.

AIRPORT CAPACITY

Airport capacity can be affected by direct routing runway exit choices that affect aircraft runway use time. Extending a landing roll would decrease airport capacity unless the exit would otherwise be on an active intersecting runway. The impact on runway capacity of adding 15 to 20 seconds to most of the landings made by pilots planning to taxi to gates located nearest the far end of the landing runway would be adverse. For example, assuming that there are 30 aircraft take-offs and 30 aircraft landings in an hour and that 15 of the 30 landing aircraft will occupy the runway 75 seconds instead of 60 seconds, each of the 15 affected aircraft would then need 1 minute and 15 seconds instead of 60 seconds for their landing and only 12 of the 15 could land in the 60 minute period. The runway could then accommodate only 57 instead of 60 aircraft per hour.

Holding actions have no practical affect on airport capacity but holding at a gate could cause an arriving aircraft to hold at a near-by location such as the apron. The resulting congestion could then cause a reduction in the speed of aircraft moving through the area. These adverse impacts can be avoided by holding in a special location.

Less than all engine taxi does not adversely affect airport capacity. However, it does create a potential take-off delay if the final engine does not start immediately and a restart cycle has to be commenced. Such an event could also delay following aircraft. No information was obtained to indicate the probability of an engine start problem applicable to starting the last engine just before take-off.

PASSENGER CONVENIENCE

All holding actions are an inconvenience to passengers. Holding at the gate before passengers have boarded is the least inconvenient. However, other incoming passengers would also be inconvenienced if the action delays another aircraft. Holding at a special location does not decrease hold time as a measure of inconvenience but does "trap" passengers in the aircraft. More passengers are inconvenienced if a gate hold delays an arriving aircraft and if the taxi times of other aircraft are increased.

Direct routing to minimize taxi time to the gate affects passenger convenience to the extent that taxi time is reduced.

Other practices and procedures, e.g., tankering, less than all engine taxi and starting engines during pushback, would have no affect on passenger convenience.

NOISE AND AIR QUALITY LEVELS

Noise environments are not significantly affected by direct routing options except for the use of reverse thrust. More noise is produced when additional reverse thrust is used to turn-off at an early exit. Reverse thrust noise is very much louder than taxi noise and is the dominant consideration. Noise environments are favorably affected when pilots extend landing rolls and use the minimum amount of reverse thrust. However, a perceivable effect on community noise environments would not result from either choice.

Nor are noise environments significantly improved by less than all engine taxi. Shutting down 2 of 4 or 1 of 2 engines reduces engine noise by 50% and results in a 3dB reduction of that particular noise. Noise exposure is perceived in terms of the much louder noises associated with aircraft take-off and landing and the beneficial effect of less than all engine taxi would not be perceived. The exception would be the unusual circumstance when taxiway locations are very close to a residential area.

Holding actions increase equipment operating times. Additional noise depends upon the increased operating time and the equipment being operated. Such increases are not perceptible in near-by communities

because of the dominant affect of take-off and landing noise. This is true even when the operating noise is an engine at idle power settings. The exception would be an airport having residential areas close to a special holding area. This does not occur at Washington National or Dulles International Airports.

Emissions are reduced and air quality is improved by less than all engine taxi. The reduction in emissions is determined by the reduction in engine operating minutes. The reduction is approximately 50% during the time half of the engines are shutdown and one-third when one of these engines is shutdown. The significance of these reductions must be considered in terms of the total amount of emissions associated with airport operation activities. Nevertheless, shutting down one or more engines for taxi has a beneficial impact on air quality. One other aspect of shutting down one or more engines and increasing the thrust on the remaining engines would be a change in the emission factors. CO and HC emission rates would decrease with a slight increase in NO_x.

Direct route choices reduce air pollution to the extent that taxi time is reduced. Tankering would have no effect on emissions except for the small amounts of emissions associated with refueling. These would be relocated from one airport to another. In addition, there could be a change in emission factors if it becomes necessary to change the power setting for taxi. Increased equipment operating times and taxi time from holding operations would, however, adversely affect air quality.

AIRPORT/AIRLINE REVENUES

The practices and procedures described in Section III would have a beneficial or neutral effect on airline and airport revenues. Fuel savings identified in Section III can be quantified using the price of fuel in 1979. Since none of these procedures would cost the airlines or airports any additional revenues, the fuel savings would all be credited as benefits.

APPENDIX I

QUESTIONNAIRE SENT TO MODELERS

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Appendix A: Questionaire for the Modelers

1. Does your model include the scheduled arrivals and departures?
2. Does your model allow for air-traffic delays upon arrival?
3. Does your model allow for air-traffic delays at the destination point, such that gate-hold benefits could be assessed?
4. Do you follow gate occupancies and have aircraft depart from a gate to make room for arriving aircraft?
5. Can you accommodate paper queues?
6. Can you add a fuel-consumption algorithm to your model, depending on the engine-start times and the taxi times?
7. Can you keep track of the number of stops made?
8. If we gave you a distribution function for the time to start the first engine, second engine, etc., could you incorporate this as part of your model to determine the fuel consumption?
9. Can you incorporate pushback times?
10. Can you incorporate the hold time before start of taxi?
11. Can you incorporate the time required for startup, warmup and checkout the the engines prior to taxi and again prior to takeoff?
12. Do you include the taxi speeds, and their range, for each taxiway?
13. Can your model perform taxi-path optimizations? Do they depend only on distance, or can they be based on the estimated taxi time, including the effect of ground traffic congestion?
14. Does your model include the time in the queue?
15. Can you add to your model the engine speed or fuel consumption, based on the ground speed and accelerations you compute?
16. Can you add the fuel consumption due to APU use, if you were given an algorithm for the startup and shutdown of the APU?
17. If the engines were to be shut down in the queue, could you keep track of their operation?
18. Can your model include holding outside the queue and gate to allow for destination delays?
19. Can you determine at which taxiway the aircraft will turnoff upon landing?
20. Can you determine the effect of reverse thrust on which turnoff runway is used?
21. Can you simulate a hookup delay such that an engine or APU must be used instead of the ground power?
22. Can you simulate towing of the vehicles?
23. Can you simulate the use of remote parking and mobile lounges?
24. Can you simulate more efficient guide-in means, such as computer controlled or mechanically actuated?
25. How much computer time is required to simulate one day of operation? (How much would the one-day simulation cost?) (How much would each variation of that one-day operation cost?)

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Appendix B: Telecon with Aviation Simulations International, Inc.

March 16, 1981: Dr. Everett Joline (516-271-6476)

ASI's simulation model is a more recent version of the Speas model. The ASI simulation proceeds from event to event, similar to the FAA model. However, so films can be produced, the ASI model has a post-processor that computes the aircraft positions on a one-second time step. Accelerations and decelerations are computed to add realism to the film.

In answer to the survey questions, Dr. Joline gave the following information:

1. The airline schedules are used as input data into a pre-processor, which alters the schedule to allow for random variations. The pre-processor also develops schedules for future airports and future operations for an existing airport.
2. The random arrival rate accounts for delays in arrival; additional delays are computed that result from the traffic at the airport being studied.
3. The interaction with other airports is not considered, but gate-hold procedures could be established in the schedule pre-processor at a cost of approximately 10 man-days. An algorithm must be developed that would govern the gate hold time.
4. If a gate is occupied upon arrival, the arriving aircraft is held on the apron until the gate becomes free.
5. Paper queues are not included at present, but they could be added with a 10-man-day effort. An algorithm would be needed to determine when the aircraft would depart from the gate.
6. Fuel consumption can be computed according to delay times, if the fuel consumption rate is assumed to be that of idle. At present delay costs are computed, with the cost being proportional to fuel consumption. If the cost is set at 1.0, the fuel consumption would be printed.
7. With the post-processor, the start/stop action of the aircraft is computed, based on the speed characteristics of each type of aircraft. Unlike the FAA model, the taxiway segments are continuous, not the 300 feet used by FAA in spacing its nodes.
8. The engine-start data can be added in 10 man-days, if given the algorithm for the starting. With a little more difficulty, any delays experienced because the engines were not ready when everything else was could also be included.
9. The pushback times are included at present.
10. The hold time before start of taxi is computed according to the availability of taxi space.
11. The time required for startup of the engines is in the program at present. The time is a fixed constant; it could be made specific to the aircraft type, with approximately 10 man-days of effort.
12. Each aircraft type has its own taxi speed.
13. The incoming and outgoing taxi routes are always assumed to be the shortest possible. If this shortest route is occupied, the queue is entered. No alternative taxiways are considered. An algorithm could be added to accommodate altternative routes.
14. The time in the queue is accumulated by airline and aircraft type. The FAA model aggregates the times in the queue over all airlines and aircraft types.
15. Detailed fuel consumption could be added to the post-processor in the one-second time step with acceleration and deceleration.
16. Fuel consumption due to APU use could be added easily, given the algorithm.
17. Again with a suitable algorithm, perhaps based on the experiences of the last aircraft to take off, the engine shutdowns during queuing could be computed.

18. The simulation has the capability of holding on an apron that is to the side of the queue. The capacities are limited according to the input data.
19. The turnoff taxiway upon arrival is determined in the airport survey. The number of aircraft of a given type turning at a given cross runway is measured in the field and entered as data.
20. The method used to turnoff at an early runway is not simulated, therefore, the use of reverse thrust is not simulated.
21. The hookup delay could be added to the model, if a suitable algorithm could be generated.
22. Towing can be simulated, using a special speed for towing.
23. Remote parking areas would be simulated as a remote gate.
24. Guide-in speeds are now given, so the effect of mechanical guide-ins can be easily assessed.
25. The computer costs are roughly $40 per day simulated, although there is a significant variation depending on aircraft types and mixes, as well as the amount of traffic.

Because the ASI model is written in SIMSCRIPT, it is more sophisticated in terms of the programming structure. Therefore, the ASI model is faster than the FAA model.

Joline as analyzed the performance data (operations) for various contracts. In addition, he has collected delay times for each airport from three airlines that keep such data. In addition, ASI has analyzed several airports.

In a followup telephone call of April 1, 1981, Dr. Joline stated that his model can provide for alternate paths if one of the taxiways is locked up. His model also has no size constraints, because the subroutines have variable dimension statements. The size is selected by the user for his particular problem. A free-format input procedure is used to facilitate input-data preparation and entry. The "random" events can be generated from the same sequence of random numbers, so alternate energy-conservation strategies can be evaluated under the identical set of circumstances.

Appendix C: Telecon with FAA Technical Center

March 16, 1981: Mr. Tony Bradley, Research Analyst X 2510
Mr. Bob Holladay, Operations Research Analyst
609-641-8200

The FAA model proceeds from event to event, with an event being computed when an aircraft arrives at a node point. The node layout is defined by the user, so multiple nodes can be used to simulate a gate.

Tony Bradley answered the questionaire as follows:

1. The published schedules or projected schedules are used for arrivals and departures. The variations around the schedule are simulated by a random number generator.
2. Aircraft delays en route are simulated by the random arrivals; delays due to the airport under study are computed in the simulation.
3. There is no interaction with other airports, so any gate-hold procedures must be simulated by changes in the schedules.
4. The model is designed to simulate gates as gate areas that always have the capacity to accept the arriving aircraft; however, a single path can be used to connect to a gate that would have the effect of limiting the gate capacity to one vehicle. The simulation would then imitate gates of limited capacity, with the arrive aircraft remaining on the apron until the parked aircraft was moved.
5. Paper queues are not included explicitly but could be included as a gate hold procedure. The program must be modified to make the gate hold depend on the current queue length.
6. At present the computer adds the delay time, so fuel consumption or values related to fuel consumption are not retained. However, the internal computations do account for each time period, so the fuel consumption could be estimated. There is no accounting of the number of times the aircraft stops and starts, so accelerations could not be included.
7. The stops cannot be counted at present. The model uses a fixed, preset speed for each taxiway, with nodes spaced approximately 300 feet apart in a typical problem. In effect, the aircraft stops at the node until the next node is clear, then advances to the new node at the average taxi speed. Average speeds could be computed and these could be related to the number of stops that would normally be made.
8. Adding engine start times and sequencing would be a major undertaking.
9. Pushback times are already in the model. They vary with gate but not with aircraft type.
10. Any delay after pushback is computed in the simulation and cannot be entered as a separate item as might be needed to simulate a gate hold. However, a gate hold could be used as an approximation. Once the aircraft enters the taxiways, the computer takes over and governs all motions by the internal algorithms.
11. Adding the engine warmup times and delays between engine starts would be a major undertaking, because there is no simulation of what occurs while the aircraft moves between nodes. There is no simulation in time, only in event sequence.
12. The taxi speed is fixed for each link between nodes. It is not aircraft-type dependent. This speed is used to determine the time from departing one node and arriving at the next.
13. The taxi path is pre-selected from each exit to each gate. There are no alternate routes to compensate for queues in the pre-selected path.
14. The model does track the times in the queues. At present, only the sum is printed.

15. Because stopping and starting are not simulated, accelerations are not simulated. Adding acceleration would be a major undertaking.
16. APU fuel consumption could not be added at present.
17. Engine shutdown during queuing could not be simulated at present.
18. Once the aircraft is in the queue, the simulation controls its motion, so diverting to a holding area due to a destination-caused delay could not be accommodated.
19. The turnoff taxiway used upon landing is determined as a distribution function for each aircraft type. The distribution is pre-selected.
20. There is no consideration given concerning the means for deceleration to make the turnoff, so reverse thrust is not tracked or computed.
21. A hookup delay cannot be simulated at present.
22. Although towing between gates is done, there is no towing beyond the pushback.
23. Remote parking/mobile lounges would be simulated as another gate.
24. The in and out taxi speeds are assumed to be the same, so a guide-in process could not be simulated at present.
25. To run the model for 16 hours of airport operation, 40 CPU minutes are required on the Honeywell 635. There is no charge for the time, so the cost is unknown.

Appendix D: Telecon with SRI International

March 16, 1981: Dr. George Couluris (415-859-3372), Program Manager
Dr. Kai Wang (415-859-5138), Programmer/Analyst

SRI's simulation model is an event-by-event model with the airport simulated by links and nodes, as done in the other detailed models. The primary difference between this model and the ASI and FAA models is the optimization of the taxi path. The optimization criterion is taxi time. The optimization process is complicated and computationally time consuming.

Dr. Wang's answers to the questionaire were as follows:

1. The basic input data for the simulation is the published airline schedule or similar data. Variations in arrivals are simulated as a random process around the schedule.
2. In addition to the delays in the arrivals, the simulation itself computes and tracks delays caused by the traffic at the airport under study.
3. Delays caused by conditions at a destination cannot be included, although gate-hold procedures can be preset or added to the model.
4. Gates cannot have multiple occupancies. The arriving aircraft would wait in the taxiway. With the optimization procedure, other aircraft would use an alternate route to avoid the parked aircraft.
5. Paper queues are not in the present model but are being considered for future modifications. The program would compute the time to arrive at the takeoff position and make the hold time dependent on the computed time. However, the strategies of the competing aircraft must be included, so the computations could become long and complicated.
6. Fuel consumption is in the model at present, based on the equations provided by Bella P. Collins at MITRE-McLean. These equations are based on a pre-selected number of engines operating and no starts/stops. The last engines are assumed to be started at the start of the runway, not the usual two or so minutes before arriving at the end of the runway.
7. Because the simulation is by event, the number of stops made between events cannot be determined.
8. See #6 above.
9. Pushback times are included.
10. Hold times at the start of the taxi are computed, if the taxiways are full.
11. Approximately two man-weeks would be required to add the fuel consumption during engine startup, warmup and checkout.
12. The taxi speed is assumed to be constant for all taxiways and all aircraft. Therefore, slow rolls cannot be considered.
13. The model does compute the optimal taxi path, with the criterion being the time from touchdown to stopping at the gate. The effects of congestion are included.
14. The time in the queue is computed. Delay times are also computed.
15. Because the model computes by event, it cannot determine the number of stops nor the accelerations.
16. The fuel consumption by the APU is not considered at present.
17. Engine shutdown during queuing could be added to the model, if a suitable algorithm could be devised.
18. There is no provision for holding after entering the gate. Once in the queue the aircraft stays in the queue until airborne.
19. The minimum landing distance is pre-determined for each aircraft. The actual taxiway used will be the optimal taxiway after the first possible after the landing distance. No consideration is given to the fact that airport capacity is decreased if the aircraft is allowed to roll down the runway.

20. The shortest landing distance is computed with thrust reversal. No computations are made to determine if less fuel would be used if the aircraft were allowed to roll. The fuel consumption due to thrust reversal is not computed.
21. Hookup delays could be incorporated if APU operation were incorporated.
22. Vehicle towing cannot be simulated. There is one speed for all taxiways and all aircraft.
23. Remote parking could be simulated by an alternate gate position.
24. More efficient guide-in procedures cannot be simulated because the taxi speed is assumed uniform.
25. At present no data are available on run times for a full day of operation. To simulate one aircraft in one operation costs approximately one dollar on the CDC 6600.

In a follow-up call to Paul Wong (415-326-6165) on April 8, 1981, some of the foregoing comments were clarified:

3. The model does not contain data on the destinations, so destination delays such as might initiate a gate hold or withdrawal from the queue cannot be simulated.
5. Paper queues cannot be simulated, but an algorithm relating the gate departure to the anticipated queuing time could be added with less than one week's effort. However, the running time of the model might increase substantially because there would be additional computations and possible re-scheduling of many flights to accomodate incoming flights. For example, the holding, departing flight might interfere with an arrival that needs the same gate. A decision would be needed concerning where to send the holding flight.
15. SRI does not think the brief increase in thrust to overcome static friction will be significant in terms of the overall fuel consumption. This opinion was derived from conversations with Bela Collins of MITRE. Therefore, SRI has not including stopping and starting as part of the simulation (except for the delays at the nodes).

Appendix E: Telecon with MITRE/METREK

March 25, 1981: Bella Collins (703-827-6956)

MITRE, in the person of Bella Collins, is developing the fuel-consumption model for the SRI taxi model. The MITRE model is based on computing the energy change in the aircraft, including overcoming wind and friction (static and dynamic), then dividing the energy change by the thrust-specific-fuel-consumption as multiplied by the aircraft velocity.

The MITRE effort has been devoted to the development of the energy concept for all phases of taxiing. Performance factors have been obtained and the basic theory, developed. The model includes runway slope, the thrust limitations of the aircraft, the characteristics of the specific aircraft and engines, thrust reversal, etc. The TSFC is entered as a function of the altitude, aircraft velocity, etc.

MITRE has no taxi model of its own, but is supporting the SRI model through the development of the taxi fuel consumption algorithm. The detail to which the algorithm is being developed will permit assessment of the fuel consumption for each start/stop operation. Therefore, Mr. Collins expects the SRI model to include the starts and stops experienced during queuing. (He suggested that I talk again to SRI and recommended that I talk to Paul Wong who is the technical leader at SRI.)

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Appendix F: Telecon with Peat, Marwick and Mitchell

March 26, 1981: Mr. Dirk Vanderbirch (415-347-9521) (also Henry Fang and Bill Dunlay)
P.O.Box 8007
San Francisco, California 94128

PMM's model was developed for the FAA and is, therefore, the same as that being used at the FAA Technical Center. Because PMM developed the model, they are familiar with the inner workings and have been able to use the model for some new circumstances such as pulling an aircraft out of the queue in response to a destination delay.

In answer to the survey questions, Mr. Vanderbirch gave the following information:

1. The airline schedules are used as input data.
2. The arrival times are varied randomly to simulate deviations from the schedule. Departure delays are a product of the simulation computations.
3. Destination delays, such as needed for a simulation of the savings due to fuel-advisory departures, are simulated according to major geographic regions of the U.S. For example, input data would show that all midwest flights are delayed.
4. Gate occupancy is tracked so two aircraft cannot occupy the same gate.
5. Paper queues are not possible now but could be added.
6. A fuel-consumption algorithm could be added, but the model does not now track or simulate starting and stopping, such as needed for Bela Collins' model.
7. The stopping and starting is not simulated.
8. Engine operation could be added to the model, if a suitable algorithm could be developed. It could even have some feedback on the basis of the time required for the previous aircraft to reach the takeoff position.
9. Pushback times are currently specified by the user for each gate.
10. The hold time before the start of taxi would be computed if caused by ground traffic; disconnect delays would be part of the pushback time.
11. The pushback times should also incorporate any delays in taxi times due to engine startup, warmup and checkout.
12. Each taxi link has an input-specified speed that is independent of aircraft type. Variations by aircraft type could be incorporated in a few mandays.
13. The model uses pre-specified taxi routes; there is not taxi-path optimization.
14. The time in the queue is computed as the simulation progresses. The data are kept disaggregated as well as aggregated. A post-processor can be used to to analyze the disaggregated data, although none is currently available.
15. Fuel consumption can be added on the basis of ground speeds and accelerations, but not on the basis of starts and stops.
16. The APU is not currently simulated.
17. The shutdown of engines while the aircraft is in the queue is not part of the present simulation. Given an algorithm for shutdown, it would be added if the algorithm used some of the parameters currently computed.
18. The model has been used to simulate having the aircraft pull out of the queue and wait for a destination clearance.
19. Taxiway usage upon landing is determined by input data for the distribution of landing distances. The data are usually obtained from field measurements. Not attention is paid to fuel consumption due to thrust reversal.
20. No attention is paid to thrust reversal, so no fuel-consumption tradeoffs can be made for the runway turnoff point.

21. There is no delay upon arrival at a gate, except if the gate is occupied. Therefore, a hookup delay and its effect on fuel consumption cannot be simulated at present.
22. Towing of vehicles from hanger to gate is simulated, but not towing to the takeoff point or some point in between. The pushback link could be made longer to simulate towing.
23. Remote parking of aircraft and the use of mobile lounges would be simulated by locating the gate at the remote parking area
24. The model assumes that the velocity on a link is independent of direction; therefore, a method of guiding the aircraft into the gate that would make the arrival speed greater than the departure speed cannot be simulated at present.
25. A 12 to 13 hour period at Atlanta requires approximately one hour of CPU time on a Harris computer, approximately 3.5 minutes of CPU time on a CDC 7600, or approximately 1.5 minutes on a Cray.

In a followup telecon (April 3, 1981) with Henry Wang, who is most closely associated with the program, and Bill Dunlay, who is a senior consultant on the program, the following points were made:

The model has already been used for the evaluation of towing in terms of the amount of congestion it causes. The model already has a gate-hold capability that depends on the expected taxi time.

The model could be modified to incorporate Bela Collins' work, taxi on fewer engines, and allowing for alternate taxi routes when the primary route is congested. Each of these three items would require approximately 4 manweeks.

Appendix G: Telecon with Gellman Associates

April [illegible], 1981: Earl Bomberger (215-884-7500)

Gellman Associates has not general model of airport taxiing. Their study on towing was based on towing data obtained from the field. The data was used in hand computations to obtain the results presented in their reports.

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Appendix H: Other Models: A Report of a Telecon with Battelle-Columbus

April 9, 1981: Mr. Vincent Drago (614-424-5129)
Battelle-Columbus

Battelle has an airspace queuing model that uses an airport acceptance rate as a function of weather and runway usage (obtained from MITRE, for example) and combines this with an arrival rate that is entered for each hour. There is no detail concerning the taxiing portion of the flight; therefore, the model cannot simulate the energy conservation measures.

Vince said that there are many airspace/airport models in existence and that they are described in

> A.R.Odoni and R.W.Simpson (MIT): Review and Evaluation of National Airspace Systems Models. FAA Report FAA-EM-79-12 (October 1979)

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Appendix I: Telecon with Landrum and Brown, Inc.

April 9, 1981: Mr. John Ernst, Principal and developer of the L&B models
Landrum and Brown, Inc. (513-721-1149)
290 Central Trust Building
Cincinnati, Ohio 45202

Notice that Landrum and Brown has moved from Cleveland. Actually, Booz, Allen and Hamilton acquired Landrum and Brown in Cleveland then divested the airport portion which moved to Cincinnati and retained the name of Landrum and Brown.

L&B have two models, which can be coupled: an airspace model and a taxi model. The taxi model consists of links and nodes, with the nodes spaced approximately 300 feet apart. The time sequence is established on an event-by-event basis. In response to the questionaire, Mr. Ernst provided the following information:

1. The model uses as input the scheduled arrivals and departures.
2. The schedule is randomized to simulate en route delays and gate delays. This part of the model calls for rescheduling of gates, a process that takes much computation time in this and the other similar models (PMM, FAA, etc.)
3. At present the model does not allow for destination delays and possible gate holds, although such a capability could be incorporated in approximately two manweeks.
4. Gate occupancy is limited to one aircraft, so an arrival could be delayed if no gates are available.
5. Paper queues are not possible at present but could be incorporated in two manweeks.
6. Engine operation and fuel consumption are not part of the model, but could probably be added in two manweeks.
7. The only start/stop data is that associated with the nodes. Stops in between cannot be followed.
8. Again, the engine operation is not part of the model but could be added in two manweeks.
9. Pushback times are currently in the model.
10. A hold time after pushback would be incorporated as part of the pushback time, or a new hold time could be incorporated in two manweeks of programming.
11. The engine start time could be added, also in two manweeks, even if the engine startup would alter the computations by adding a delay for engine checkout before takeoff.
12. Taxi speeds are dependent on aircraft but are constant for all taxiways.
13. Although there is no provision for taxi-path optimization, alternate paths are used if the normal path is congested.
14. The time in the queue is computed and is part of the output.
15. Fuel consumption can be added to the simulation, but is not available at present.
16. APU fuel consumption could be similarly added.
17. Given an algorithm for engine usage, engine shutdown could be added to the model in two manweeks.
18. The model does not now permit pulling an airplane out of the queue.
19. The turnoff after landing is determined from the measured or estimated distribution of landing distances peculiar to each aircraft type.
20. No accounting is taken of the means used to select the turnoff, such as reverse thrust. However, if a long roll were to be advantageous to an arrival, the long roll is taken to minimize taxi time.

21. A hookup delay upon arrival at a gate is not simulated at present.
22. Towing can be included in a simulation as the model now stands.
23. Remote parking and mobile lounges would be simulated by a new gate placement.
24. At present, the taxi speeds are independent of direction, so a more efficient guide-in procedure can have only the same taxi speed at the gate link as the outgoing vehicle has.
25. The simulations are performed on the companies Harris supermini-computer in approximately 3 to 4 minutes of CPU time for an 8 to 12 hour simulation at a cost of approximately $50 to $100.

APPENDIX J

AIRLINE IDENTIFIERS

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APPENDIX J

AIRLINE IDENTIFIERS

AA:	American Airlines
AF:	Air France
AK:	Altair Airlines
AL:	U.S. Air
AL:	Allegheny Commuter
BA:	British Airways
BN:	Braniff Airlines
CB:	Commuter Airlines
CE:	Air Virginia
CG:	Colgan Airways
CK:	Liberty Airlines
CO:	Continental Airlines
DL:	Delta Airlines
EA:	Eastern Airlines
KC:	Aeromech
ML:	Midway Airlines
NA:	National Airlines
NC:	New Air
NW:	Northwest Airlines
OZ:	Ozark Airlines

PA:	Pan American Airlines
PI:	Piedmont Airlines
PM:	Pilgrim Airlines
QH:	Air Florida
RC:	Republic Airlines
TW:	Trans World Airlines
UA:	United Airlines
VL:	Mid South Commuter Airlines
VM:	Ocean Airways
WA:	Western Airlines